SECTION 7

RESEARCH AND DEVELOPMENT

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The majority of the research and development (R&D) conducted at the Hanford Site, especially during the early decades, was connected directly or indirectly to the production of plutonium. From the outset, the Hanford Site's main contribution was not innovative research but the production of fissionable material for bombs as quickly and cost efficiently as possible (Findlay and Hevly 1995). R&D efforts focused on increasing the amount of plutonium being produced, increasing the life of equipment, improving health and safety for the workers and public, and reducing costs. As the years progressed, R&D staff steadily increased their work away from plutonium production and began working for other clients outside the Hanford Site.

Types of Research
(Adapted from AEC 1960)

Basic Research: Primary aim is fuller understanding of the subject under study rather than any practical application or immediate useful goal.

Applied Research and General Development: General research undertaken with the clear probability that it will have a useful end result.

Project Development: All efforts devoted to the solution of specific problems and producing an end result.

Process and Product Improvement: Concerned with lowering costs and increasing the efficiency of products or systems that have been developed and put into production or operation.

R&D efforts at the Hanford Site covered a wide variety of topical areas including the physical sciences (metallurgy, chemistry, atmospheric sciences, etc.); medicine, biology, and related life sciences; improved nuclear reactors and reactor systems; and energy applications. Within each of these areas, R&D could fall anywhere from basic research to process and product improvement. The type of research directly impacted the staff and facility requirements. Basic research would typically require theoretical scientists and laboratory settings, while process and product improvements might involve engineers, technicians, and test facilities such as test reactors and high bays.

The federal government has historically been a major funding source for R&D of national importance. Major areas include national defense, energy, and basic science. The U.S. Department of Energy (DOE) and its predecessor organizations have contributed significantly to these efforts across the nation. The Hanford Site has played a small but significant role in this national research agenda. Understanding the research problems undertaken and the accomplishments achieved at the Hanford Site contributes to the historical record on government funding of R&D.

This narrative relates the history and accomplishments of R&D activities at the Hanford Site between 1944 and 1990. The focus is the work the R&D staff assigned to the Pacific Northwest National Laboratory (as it is presently known) and its predecessor organization, the Hanford Laboratories, conducted. The narrative also includes the R&D work Hanford staff conducted before the Hanford Laboratories was formed.

Our goal in this narrative is to give the reader a basic understanding of the types of R&D performed

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Divider Page Photo: Early Researchers at the Applied Fisheries Laboratory, circa 1944 (Becker 1990, p. 63) at Hanford (see sidebar box), especially those not related to the production of plutonium. Research directly related to plutonium production is also discussed here and more fully described in the sections on production: Fuel Manufacturing, Reactor Operations, Chemical Separations, and Plutonium Finishing. Our secondary goal is to link R&D activities to buildings and properties contributing to the Hanford Site Historic District. The physical structures that housed research teams play a vital role today in comprehending R&D at the Hanford Site.

Historical Context

The nature of R&D at the Hanford Site changed over the years in response to the national and international context in which events occurred. This context helped define eras different from those described in the other sections of this book, which are defined by the production of plutonium. The R&D eras were affected by such events as the rise of civilian nuclear power, the environmental movement, the energy crisis, and the information revolution. The dates of the eras are not precise but are instead indicators of generally when events had the most effect on R&D at the Hanford Site. Some of the events overlapped as indicated by the dates. The eras that affected R&D at the Hanford Site were:

- Pre-World War II (Pre-1942)
- Manhattan Project Era (1942-1946)
- Weapons Complex Era (1946-1988)
- Energy Era I (1955-1970)
- Energy Era II (1971-1988)
- Cleanup Era (1989-present)

Pre-World War II (Pre-1942)

It was not until the late 1800s that a significant scientific community emerged in the United States. This community was primarily supported by industry, universities, and independent research centers with industry in the forefront. By the beginning of the 20th century, industrial research was decentralized and competitive, major institutions performed research and technical services, and government work was contracted out, usually to universities. Basic research and applied research, especially military, were in dire straits on the eve of World War II (Kleinman 1995, Smith 1990).

The story of the development of nuclear technology is one of the major R&D stories in the history of the world and is central to the story at the Hanford Site. Chapter 1 sketches this historical tale and the introduction of fission to the United States. Although the U.S. Government was interested in the subject of fission and wanted to be kept informed about any progress in the field, it would not devote any funding for research until more information could be obtained. It was not until 1940, after several research facilities in universities across the country had made significant progress on the fission problem, that federal funding for research was anticipated (Hewlett and Anderson 1990).

Manhattan Project Era (1942-1946)

All efforts of developing atomic energy as a power source were diverted toward developing an atomic weapon when the United States entered World War II (Groves 1983). In 1942, President Roosevelt agreed the U.S. Army Corps of Engineers should be in charge of designing plans to develop atomic weapons. Many physicists in America were soon involved in solving the complex problems surrounding production of radioactive isotopes, isotope refinement and separation, and weapon design.

By 1945, this massive R&D effort had proven successful. The R&D teams at the University of Chicago and Los Alamos developed the technology. The engineers and others at the production sites of the Oak Ridge Reservation and the Hanford Site produced the isotopes. The scientists and engineers at Los Alamos designed and assembled the test bomb, Trinity, and those used at Hiroshima and Nagasaki.

Weapons Complex Era (1946-1988)

Following the end of World War II, the Cold War began and efforts commenced to increase and improve the nuclear arsenal. Weapons designers first increased atomic bomb yields, then developed the new more powerful hydrogen bomb (Rhodes 1995). As nuclear weapons technology advanced, the government embarked on an aggressive weapons testing program that released large amounts of radionuclides into the environment (Hacker 1994). These events, in concert with a generally increasing awareness of the dangers of radiation, stimulated considerable R&D on human and environmental health effects of radiation.

Developing the atomic bomb had started out as a theoretical academic question and ended in a tangible result. This result of the Manhattan Project led the federal government to place an increasing priority on science, not only for defense but in the other federal agencies as well.

Energy Era I (1955-1970)

In early 1946, just a few months after the bombings of Hiroshima and Nagasaki, the U.S. Congress passed the Atomic Energy Act. This legislation called for the development of federally funded research programs to secure scientific and technical accomplishments in the field of nuclear energy. This was a new and exciting field, and private industry expressed interest in using nuclear technology for power production. Private industry, however, made little advancement in the nuclear energy field until the 1950s. Two reasons commonly cited are the control the government maintained on nuclear materials and the great technological risk that industry was unprepared to assume (Hewlett and Holl 1989).

President Eisenhower gave a boost to nuclear energy with his Atoms for Peace Initiative of 1954. The U.S. Congress amended the Atomic Energy Act in 1955 to provide funds for a series of demonstration projects. Demonstration plants were constructed, the Navy began using nuclear technology to power its submarines and ships, and the nuclear energy industry began to develop. By the 1960s, utilities across the nation were constructing nuclear power plants, and expectations were high throughout the world for this new source of power. Before 1966, electric utilities had ordered fewer than ten reactors total. In 1966-1967, that number quadrupled. After declining slightly in 1969, nuclear power reactor orders peaked in 1972-1973. Government and industry funded substantial R&D efforts to increase the efficiency and safety of nuclear energy.

Also during this era, alternative uses for nuclear technology were being sought. Project Plowshare represented one of the more commercial efforts related to alternative uses. R&D efforts within this program were associated with using nuclear explosive devices for large-scale construction and other non-military purposes, such as using nuclear devices to construct canals, to improve oil exploration efforts, and for mining. The U.S. Congress committed $3M to the program in 1958 and 1959, but the program fizzled shortly thereafter as a result of President Eisenhower's moratorium on nuclear testing (Hewlett and Holl 1989; O'Neill 1995, 1998).

Energy Era II (1971-1988)

This era was marked by the energy crisis of the early 1970s, which was related to the rapid increase in oil prices from Middle East suppliers. The crisis set off an unprecedented growth in R&D work related to non-carbon energy sources, such as nuclear, wind, and solar. The breeder reactor program dominated R&D efforts related to nuclear energy.

Also characteristic of this era was the increase in environmental awareness and demands for environmental protection (see Balogh 1991, D'Antonio 1993, Pope 1998, Wellock 1998). One significant impact of the environmental movement on the Hanford Site was a rapid rise in the number of laws and regulations governing nuclear technology and radioactive waste management. R&D efforts were increasingly needed to assist in developing regulatory guidelines as well as developing waste management technologies. The environmental protection movement placed pressure on the Atomic Energy Commission, which had taken over from the U.S. Corps of Engineers in 1947 to manage the Manhattan Project sites. This pressure led to the splitting of the Atomic Energy Commission in 1975 into the Energy Research Development Agency and the Nuclear Regulatory Commission.

Nuclear power reactor construction peaked in 1974 as the industry faced continued pressure from new regulations, high interest rates, increased public scrutiny, and large cost overruns. This marked the start of a downward spiral for nuclear energy that was furthered by the Three Mile Island incident in 1979 and the Chernobyl meltdown in 1986. Budgets for nuclear-related R&D suffered accordingly.

Recognizing that earlier projections for recycling waste were grossly exaggerated and because of the lack of public confidence in industry's ability to deal with waste, the U.S. Congress passed the Nuclear Waste Policy Act in 1982 (42 USC 10101). It relieved industry of the responsibility for waste disposal and identified the need for long-term storage of high level radioactive waste. This Act initiated a variety of efforts to develop a national repository, first in Kansas, and later at a variety of locations, including the Hanford Site. R&D efforts were needed to determine locations acceptable for long-term storage of waste as well as to develop systems for managing and containing the wastes.

Finally, the environmental movement had another important effect on R&D: the public's growing interest in and concern about nuclear technology. This increased the number of studies relating to the potential effects and risk of radionuclides and nuclear power generation.

Cleanup Era (1989-present)

During the 1970s and 1980s, environmental concerns heightened regarding contaminant releases to waterways and lands and their impact on people. Contamination discoveries such as those at Love Canal in New York State, where residents were exposed to harmful chemicals that had been dumped in the nearby Love Canal, and Times Beach, Missouri, where dioxins had been mixed with tar and sprayed on roads throughout the community, alarmed many. These events contributed to the passage of the *Comprehensive Environmental Response, Compensation, and Liability Act*, better known as the Superfund, and a rampant increase in cleanup of contaminated lands across the nation. However, because the DOE complex was still focused on nuclear weapons production and its high security prevented outside scrutiny and pressure for cleanup, the DOE sites experienced little impact from the environmental cleanup movement until the late 1980s.

By the end of the 1980s, events converged to move DOE into its own era of cleanup. The 1986 Chernoybyl nuclear power plant explosion in the Soviet Union led to a general opening of DOE's nuclear production facilities to outside inspection, especially at the Hanford Site where design similarities with the N Reactor gave great cause for concern. By the late 1980s, the cold war was waning and the need for nuclear weapons production, especially plutonium from the Hanford Site, disappeared. Pressure from anti-nuclear advocates led to the eventual shutdown of the Hanford Site production facilities and demand for cleanup.

During this period, the Environmental Protection Agency began pressuring federal agencies to sign federal facility compliance agreements, which were legally binding agreements between regulators and agencies that set standards and schedules for compliance with environmental statutes. The Hanford Site, under the leadership of Michael J. Lawrence, was the first DOE site to sign a compliance document in 1989, which is now in the third revision (Ecology 1994). As cleanup activities commenced, recognition of the enormity and complexity of the cleanup problem associated with radioactive wastes identified a need for new technologies to characterize, monitor, and remediate contamination (Congress 1991).

Organizational and Operational Setting

Over the years, the Hanford Site has had several contractors manage the day to day operations as well as conduct R&D. E.I. Du Pont de Nemours and Company and the General Electric Company were responsible for all activities at the Hanford Site. In 1965, however, the Atomic Energy Commission decided to disperse the activities among several contractors. The Battelle Memorial Institute assumed responsibility for the R&D activities at the Hanford Site. The sidebar box shows the directors responsible for R&D at the Hanford Site.

E.I. Du Pont de Nemours and Company

Directors of the Research Laboratories		
Name	**Company**	**Years**
Herbert M. Parker	General Electric Company	1953-1965
Sherwood L. Fawcett	Battelle Memorial Institute	1965-1967
Fred W. Albaugh	Battelle Memorial Institute	1967-1971
Ronald S. Paul	Battelle Memorial Institute	1971-1973
Edward L. Alpen	Battelle Memorial Institute	1973-1975
Tommy W. Ambrose	Battelle Memorial Institute	1975-1979
Douglas E. Olesen	Battelle Memorial Institute	1979-1984
William B. Wiley	Battelle Memorial Institute	1984-1994

As has been thoroughly documented elsewhere (Thayer 1996), the success of the construction and startup of the Hanford Site by E.I. Du Pont de Nemours and Company can be accredited to Du Pont's organizational and managerial characteristics. The most important, for purposes of this section, was Du Pont's emphasis on industrial research and development. In the 40 years before its wartime assignment at the Hanford Site, Du Pont had made research the principal basis for its products and resulting income (Du Pont 1946a, Thayer 1996). This organizational emphasis on R&D encompassed all aspects of Du Pont's construction and management of the Hanford Site.

The Du Pont departments listed below were the key organizations responsible for R&D at the Hanford Site during the Manhattan Project.

Instrument Department was responsible for the maintenance of all project instruments as well as new installations and alterations to existing equipment and instrument development (Du Pont 1946b).

P Department was in charge of process improvement, provided the consultation and checking services for the Construction Division and Pile Operations, and developed and expanded the Fish Lab. Operations of the P Department were located at a variety of buildings including 107, 146-F, 303, and 305 (Du Pont 1946d, 1946e).

S Department was concentrated in the 200 Areas. This department was concerned with all aspects of separation facilities and isolation buildings. Another very important function of this group was the emphasis on meteorological and climatological research. The meteorology group worked closely with the chemical separations personnel to schedule dissolver operations when weather conditions were the safest for releases from those operations. They also studied wind direction and velocity, precipitation, conducted forecasts, and determined stack-to-ground dilution factors. This departmental role expanded when airborne waste began to be linked to vegetation contamination. The S Department was concentrated at the 622 Meteorology Complex (Du Pont 1946e). For information on the 622 Meteorological Complex, see the Historic Property Inventory Form in Appendix B on the Internet.

T Department was responsible for all plant process technology, operated the plant control and development labs, maintained the Technical Manual and the Operating Standards, issued reports of technical progress, provided isolation technology and plant assistance, and produced canning, reactor, and separation technology. The T Department, along with the Fish Labs, also carried out Columbia River studies to ensure adequate control of effluent materials for the protection of fish and other forms of aquatic life. These studies were later taken over by the Health Instruments Section (Du Pont 1946f, 1946g).

Medical Department/Health Instruments Section was a specialized safety and technical group primarily concerned with the problems of occupational and public health hazards. This group was responsible for reporting hazard conditions, assisted the Production and Technical Departments in determining safe working conditions from radiation, recorded personnel exposure, and maintained medical records. A variety of radiation monitoring devices (Betty Snoop, Cutie Pie, pencils, etc.) and medical examinations (urine samples, thyroid checks, etc.) were used to ensure Hanford worker radiation protection. This group was concentrated in a variety of buildings such as 231-Z, 292-T, 321-Complex, 3706, 3745-A/B, and 3746 (Du Pont 1946c). For information on these buildings, see their Historic Property Inventory Forms in Appendix B on the Internet. For more information on the Medical Department and its Health Instruments Section, see the Worker Health and Safety Section.

General Electric Company

After the General Electric Company assumed the primary contract for operation of the Hanford Site in 1946, R&D activities were reorganized and expanded (see Table 2-7.1). During the first postwar expansion from 1947-1949, plutonium production was of primary importance at the Hanford Site. However, because of the Atomic Energy Act regulations, which were issued in 1946, the peaceful uses of atomic energy also had to be explored.

Table 2-7.1. *Hanford Site Research and Development Personnel, 1946-1957*

Year	Percent of R&D Personnel
1946	<1
1947	1
1948	5
1949	7
1950	7
1951	9
1952	9
1953	10
1954	9
1955	8
1956	9
1957	9

R&D activities carried out by General Electric included radiobiology; radioactive isotope production; design and development of reactors, water treatment plants, separation facilities and equipment; radiological and meteorological monitoring; aquatic life studies; and biological studies of animals using radioactive elements.

In 1953, all departments conducting R&D were consolidated under one new organizational name–the Hanford Laboratories – to reflect their primary mission, research. Research facilities were not necessarily identified as "laboratories" before this time but rather were distributed throughout the production organization facilities. Construction on the Hanford Laboratories complex in the 300 Area was completed in 1953 (GE 1954a). This concentration of research groups in one primary area created better communication and eliminated duplicate research. The Hanford Laboratories continued research and development programs in support of irradiation processing, chemical processing, waste management, and reactor fuels preparation. Laboratory personnel also provided advanced research in the physical and life sciences as well as radiation monitoring. These studies took place onsite at a variety of buildings, laboratories, and farms because the 300 Area initially did not have the capacity to handle all research activities.

Battelle Memorial Institute

In 1963, General Electric, which had operated the Hanford Laboratories since 1946, announced that it wished to end its contract, citing potential conflict with its desire to pursue work in the commercial nuclear field. In 1964, the Atomic Energy Commission decided to split the Hanford Site operating contract among several different contractors. Battelle Memorial Institute, a research and development organization from Ohio submitted a proposal to operate the Hanford Laboratories.

Battelle had a longstanding relationship with the Atomic Energy Commission and had played a significant role in the Manhattan Project with 400 staff working round the clock on fuel rod fabrication, alloy development, and other projects. These wartime projects were followed by numerous Atomic Energy Commission projects, several of which were in collaboration with the Hanford Laboratories (Boehm and Groner 1986).

In its proposal, Battelle committed to invest the net fee resulting from the contract plus an initial appropriation of $5 million of its own funds into laboratory facilities to promote research and development in the Tri-City and Pacific Northwest areas (Boehm and Groner 1986, p. 72). In return, Battelle asked for the ability to use the laboratories for private research. It would eventually take 2 years to negotiate the finer points of this private use contract with the Atomic Energy Commission, but it would prove to be well worth the effort in terms of benefitting both the government and private industry by sharing facility costs and expertise.

On May 28, 1964, Senators Jackson and Magnuson announced that Battelle had been awarded the contract to operate the Hanford Laboratories. When Battelle took over in 1965, the research facility was separated from Hanford Site operations and renamed the Pacific Northwest Laboratory. The government also issued Battelle a Use Permit, which enabled Battelle to conduct research for government agencies as well as private companies (PNNL 1999). Figure 2-7.1 shows the announcement of Battelle's selection to operate the laboratories at the Hanford Site.

The initial mission of the Pacific Northwest National Laboratory, as it is currently called, was to focus on nuclear technology and the environmental and health effects of radiation. The Use Permit enabled Battelle to do research for others, obtain patents, license technology, and develop partnerships with industry. By the 1970s, the Pacific Northwest National Laboratory's mission had evolved to include a wide range of services and research in the areas of energy, environment, and the economy (PNNL 1999) (see sidebar box for listing).

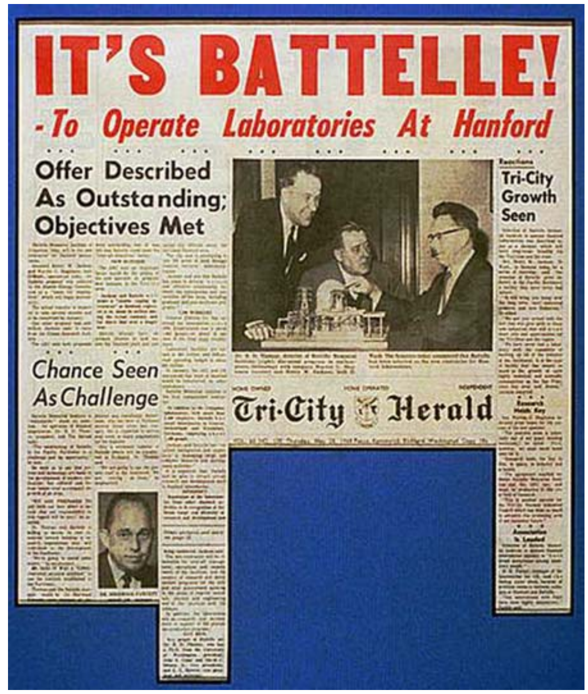
IT'S BATTELLE!
- To Operate Laboratories At Hanford
Offer Described As Outstanding; Objectives Met
Tri-City Growth Seen
Chance Seen As Challenge
Tri-City Herald

Figure 2-7.1. *Article Appearing in the Tri-City Herald Announcing Battelle as the New Operator of the Laboratories at the Hanford Site, May 1964*

Other Research Contractors

After 1965 when numerous contractors took over various operations at the Hanford Site, each of these contractors had their own R&D organizations to experiment with new materials, process improvements, and methods. Because these advancements were typically restricted to production, we have not covered them in this section.

In one case, however, an organization other than Battelle did take on a major R&D effort not related to production. The Hanford Site was selected as the location for the Fast Flux Test Facility, a prototype breeder reactor. Westinghouse Corporation won the contract in 1970 to construct and operate the Fast Flux Test Facility. Approximately 800 Battelle employees who had been working on the Fast Flux Test Facility Project up to the time the contract was awarded transferred to Westinghouse.

Important Areas of Research

When the Hanford Site was chosen to produce plutonium, questions immediately arose about the possible environmental impacts. Radiation tolerance limits were not completely understood in World War II America. No tolerance limits were established for the hazards that would be encountered during production or the number of radionuclides that would be produced. Scientists did not comprehend how these isotopes would behave in soluble or insoluble form. It was uncertain if they entered the body through inhalation, ingestion, or absorption through the skin. They did not know how the isotopes would concentrate in the food chain in plants, insects, fish, birds, mammals, and eventually humans. Furthermore, very few studies of the sandy earth and extreme winds of the Columbia Basin had been undertaken. This compounded the uncertainties of the entire project and forced almost immediate inquiry into broad biomedical and ecological research (Gerber 1992a, Stannard 1988). Thus, research was performed concurrently with construction and production at the Hanford Site. Indeed, wastes were present in the area's air, ground, and water. Emissions occurred repeatedly above levels that were then defined as permissible or tolerable. Radioactive substances entered the food chain through both the air and river and were exacerbated by dust storms and construction activities. To ameliorate some of these problems, Hanford researchers first focused on worker health and safety followed by environmental studies.

An immense array of research and development has been conducted at the Hanford Site over the years. Hanford's depth and breadth of nuclear expertise created a demand for Hanford staff as the nuclear industry evolved. Studies in the physical and biological sciences have been carried out at the Hanford Site since the early 1940s. Human health and the health of the surrounding environment provided the primary focus for these early studies. Potential hazards to these groups provided the foundations for extensive biological and radiological programs at the Hanford Site.

Research and Development Capabilities in the 1970s of the Pacific Northwest National Laboratory
(PNNL 1999)

Air & Water Pollution
Alloy Development
Analytical Chemistry
Applied Mathematics
Aquatic Biology
Atmospheric Sciences
Biomedical Science & Technology
Biophysics
Catalysis-Surface Chemistry
Cellular & Molecular Biology
Ceramics & Cements
Chemical Development & Processes
Comparative Pathology
& Physiology
Composite Materials
Computer Simulation & Systems Analysis
Computer Technology
Corrosion Technology
Ecology-Radioecology
Electrochemistry
Electrochemical Devices, & Systems
Electronic Devices, Circuits
& Systems
Energy Conversion Processes
Environmental Sciences
Fluid Mechanics
Food Technology
Geosciences
Graphite Technology
Heat Transfer
Hydraulics
Hydrology
Industrial & Applied Chemistry
Industrial Economics
Inhalation Toxicology
Inorganic Chemistry
Instrumentation
Laser Technology
Marine Science & Technology
Materials Fabrication
Materials Separation & Purification
Mechanical Components & Devices
Microscopy: X-Ray, Optical & Electron
Mineralogy
Nondestructive Testing
Nuclear Economics
Nuclear Fuels Development,
Processing & Separations
Nuclear Instrumentation
Nuclear Physics
Nuclear Reactor Technology
Nuclear Reactor Materials
Nuclear Safeguards Evaluation
Operations Research
Optics
Organic Chemistry
Process & Physical Metallurgy
Physical Chemistry
Plant Nutrition
Process Development
Radiation Biology
Radiation/Irradiation Effects on Materials
Radiation Shielding & Protection
Radioactive Wastes Processing & Disposal
Radio & Radiation Chemistry
Radiobiology
Radioisotope Technology & Applications
Radiological Science & Technology
Regional Economics
Seismology
Semiconductors-Solid State Devices
Solid State Physics
Spectroscopy
Statistics
Systems Development & Analysis
Theoretical & Applied Mechanics
Theoretical & Mathematical Physics
Thermodynamics
Toxicology
Ultraprecise Measurement Methods
Ultrasonics
Water Treatment, Use & Recovery
Welding-Joining Technology

Major areas of R&D were conducted at the Hanford Site outside of producing plutonium for weapons. Charts at the end of this section list both the biological and ecological research projects as well as the physical research projects at the Hanford Site from 1951-1990.

Eight main areas of R&D were important at the Hanford Site: detecting radiation, human radiation experiments, meteorology and atmospherics, applied fish studies, radioactivity field and reactor effluent studies, environmental and biological monitoring, radiobiology, and inhalation (pulmonary radiotoxicology) studies.

Detecting Radiation

Detecting radiation was one of the first areas of research initiated at the Hanford Site and was essential to secure the health and safety of Hanford workers and area residents. Although good plant construction and design was necessary to protect workers and the environment from any possible dangers, Hanford managers were aware that an onsite team of health physics experts was needed for their radiation detection program (Gerber 1992b).

The first health protection and instrumentation team arrived at Hanford in early 1944. They researched the biomedical effects of ionizing radiation and devised a variety of methods of shielding and monitoring radiation workers (see the Health and Safety Section). They quickly established themselves in an organization known as the Health Instruments Section. The Health Instruments Section was instrumental in defining and measuring radiological hazards, safety procedures, and developing and calibrating instruments (Gerber 1992a, 1992b; Stannard 1988). The Health Instruments Section was incorporated into Du Pont's Medical Department. The Medical Department/Health Instruments Section specialized in safety and the problems of occupational and public health hazards.

The Health Instruments staff placed a number of new and unique radiation detection instruments into use at the Hanford Site (Gerber 1992a, 1992b; Howell et al. 1989). These included integrons (air monitors), gas and liquid sampling vessels, Geiger-Mueller counters, and other devices for personnel monitoring. A variety of radiation monitoring devices and medical examinations (urine samples, thyroid checks, etc.) were used to ensure worker radiation protection.

To assist in improving the quality and decreasing the expense of radiation protection, many portable health physics instruments were designed, modified, or fabricated onsite (see Table 2-7.2). Portable health physics instruments have always been at the forefront of maintaining radiation control programs at the Hanford Site. The two functional types are those designed to monitor contamination and those designed to measure exposure rates. Most R&D of portable health physics instruments occurred in the 318, 3745, 3745-A, 3745-B buildings (Howell et al. 1989, Roesch 1964).

Human Radiation Experiments

In early 1942, officials of the Manhattan Project realized they would need a special medical program to monitor the exposure of scientists and workers to materials produced during plutonium production. Determining adverse health effects were a priority for safety as well as the risk that any excessive radioactivity spread outside the facilities might be detected, which could compromise the security and with it the schedule of weapons production.

Human radiation experiments were one of the most controversial R&D activities undertaken. Government sponsored human radiation experiments occurred within the broader context of biomedical science, which encompassed experimental research as well as the diagnosis and treatment of disease. The Corps and its successors also had related interests in radioecology, radiological warfare, civil defense, and nuclear fallout. The chief objectives were to determine the biological effects of radioactive material, measure doses from injected, ingested, or inhaled radioactive substances, or measure the time it took such substances to pass through the body (also called uptake studies). At Hanford, these were manifest in a variety of formats, and research subjects included Hanford Site employees, medical patients, prisoners, and routine monitoring of area children. The experiments at the Hanford Site were divided into two main subject areas, environmental releases and human plutonium injections. A few of the Hanford studies will be discussed below. For more information on complex-wide experiments, see DOE 1995a, 1995b; CEC 1986; and Welsome 1999.

Table 2-7.2. *Portable Instruments Used to Monitor Contamination and Measure Exposure Rates at the Hanford Site, 1944-1988*

Name of Instrument	Type of Detection	Date Intro.	Designed at Hanford	Modified at Hanford	Fabricated On/Off Site	Date Retired
Contamination Monitoring Equipment 1940s						
Victoreen GM	Beta-gamma	1944-49		Yes	Off	1950-59
Eltronics GM	Beta-gamma	1944-49				1950-59
Victoreen 389C (Thyac)	Beta-gamma	1948		Yes	Off	
Zeus	Beta-gamma	1947				
Sandy	Alpha	1944				1950-59
Portable Poppy	Alpha	1949				1950-59
Exposure (Dose) Rate Monitoring Equipment 1940s						
Beckman	Beta-gamma	1944				1950-59
Hanford Cutie Pie (CP)	Beta-gamma	1948	Yes (1944)		Off	1950-59
Juno	Alpha-beta	1945				1980-89
Epsey Junos	Alpha-beta	1949				1950-59
BFP Instrument	Neutron	1948				
The Neut	Neutron	1948				1950-59
Contamination Monitoring Instruments 1950s						
Nuclear Chicago GM	Beta-gamma	1950				1950-59
Victoreen 389 CD GM	Beta-gamma	1953				1960-69
HAPO GM	Beta-gamma	1956	Yes		Off	1970-79
Scintillation Portable Poppy	Alpha	1955				1970-79
Victoreen Alpha Meter	Alpha-beta	1950				
Zeuto	Alpha-beta	1950				
Chicago Samson	Alpha-beta gamma	1955				
Exposure (Dose) Rate Monitoring Instruments 1950s						
Red Face Juno	Alpha-beta	1950	Yes		On	1980-89
Yellow Face Juno	Alpha-beta	1950	Yes		On	1980-89
Improved Cutie Pie (CP)	Beta-gamma	1954	Yes		Off	
Improved Juno	Alpha-beta	1954	Yes		Off	
Totem Pole		1950s	Yes		On	
TPC			Yes			
LPC			Yes			
BFP		1958				1960-69
Contamination Monitoring Instruments 1960s						
Eberline E-120 CRM	Alpha	1968	Partial		Partial	
Eberline E-140 CRM	Alpha	1969	Partial		Partial	
Radeco 225 CRM	Alpha	1969	Partial		Partial	1970-79
Exposure (Dose) Rate Monitoring Equipment 1960s						
HPC	Gamma	1961	Yes		On	
BFQ	Neutron	1963	Yes		On	1970-79
Snoopy	Neutron	1969				
Contamination Monitoring Instruments 1970s						
Eberline PAC-6	Alpha	1977				
GM detector	Beta	1972				
GM detector (pancake probe)	Beta	1972				
Exposure (Dose) Rate Monitoring Instruments 1970s						
Eberline Teletector	Gamma	1972				
Eberline R0-3B	Beta	1975				
Bumblebee (modified Eberline R0-3B)	Alpha, Beta Gamma	1976				
Contamination Monitoring Equipment 1980s						
Bicron "Surveyor"	Alpha	1984				
Exposure (Dose) Rate Monitoring Instruments 1980s						
Johnson "Extender"	Gamma	1984				
Victoreen Model 325		1985	Yes		Off?	
"Black Widow"	Alpha-beta gamma	1980				

In 1949, a voluntary tissue sampling program was initiated to analyze the deposition of plutonium in humans. Bone, liver, and lung tissue were obtained from former employees during autopsies. This program grew into the current U.S. Transuranium Registry administered by Washington State University. In 1951, fourteen subjects participated in a study that examined the percutaneous absorption of tritium oxide. As a result of this study, researchers recommended a 50 percent reduction in the maximum level for atmospheric tritium oxide (DeLong et al. 1954). To determine uptake by the human thyroid, eight Hanford workers consumed milk during 1963 from dairy cows fed iodine 131 (Watson et al. 1964). From 1963-1971, 64 inmates at the Washington State Penitentiary received x-rays of their testes to examine the effects of ionizing radiation on human fertility and testicular function (CEC 1986, Welsome 1999). And children were subjected to routine monitoring in whole-body counters to determine what kinds of radionuclides may be present in their bodies from living in the vicinity of the Hanford Site and eating locally grown produce (Honstead 1967). Many of the human radiation experiments performed with research monies by the Atomic Energy Commission and its predecessor agencies would not currently be allowed under more rigorous research guidelines. Many of these studies were developed in conjunction with larger research programs such as meteorology and atmospherics, inhalation studies, health physics, and radiobiology.

Meteorology and Atmospherics

Because process gas would be released from the chemical separations plants, temperature and other atmospheric conditions were environmental safety concerns for the Hanford Site from the beginning. A meteorologist was sent to inspect the Hanford Site and its topographical features when construction first began in 1943. Soon after the Hanford Site designed a comprehensive meteorological and atmospheric research program.

Preventing harmful effects of plutonium production by-products required the continued study and monitoring of meteorological conditions. The S Department, located in the 622 Complex, was responsible for Hanford's meteorological and atmospheric research program. The Meteorology Group within the S Department worked closely with the chemical separations staff to schedule when process gas could be released during dissolver operations. This depended on the most favorable weather conditions. For information on the 622 Meteorological Complex, see the Historic Property Inventory Form in Appendix B on the Internet.

Du Pont's S Department built the first meteorology tower in 1944. The tower was used to study wind direction and velocity, precipitation, forecasts, and determine the stack-to-ground dilution factors. This departmental role expanded due to concerns with airborne releases and resulting contamination of vegetation.

Du Pont's meteorological and atmospheric research program became more comprehensive over time. Between the years 1959 and 1974, more than 300 atmospheric studies were completed involving surface and elevated releases of tracers (Nickola 1977, Nickola et al. 1983, Ramsdell et al. 1985). Tracers were used to track the movement of stack effluents across the landscape. These planned experiments were necessary to analyze atmospheric conditions and develop tracer techniques. Charles E. Elderkin measured the dispersion characteristics of the atmosphere with respect to particles in one of the largest atmospheric diffusion experiments ever conducted. In addition to Elderkin, Jake Hales was another eminent researcher in the field of meteorology and atmospherics (see sidebar box).

Before the 1950s, most radioactive material releases into the air were the result of operating processes or were accidental. However, one release called the "Green Run" was a planned experiment. It occurred in December 1949, 3 months after the Soviet Union detonated its first nuclear device. The purpose of the experiment was to measure how an airborne release of radioactive materials spread through the environment in hopes of monitoring the Soviet nuclear weapons program. During this experiment, "green" fuel still containing large amounts of radioactive iodine was discharged through the stacks of T Plant. Weather conditions at the time of the test were unfavorable and radioactive gases were dispersed over populated areas. The radioactive iodine came to rest on surrounding ground, vegetation, and water. A 1993 review of classified materials revealed that this test was not "intended to be a radiation warfare experiment or a field test of radiobiological effects on humans" (GAO 1991).

CHARLES E. ELDERKIN - HANFORD SITE 1959-PRESENT

Charles Elderkin has contributed to science at the Hanford both as a research scientist and as the Manager of the Atmospheric Sciences Program. His research has focused the physics and chemistry of clouds and precipitation, evaluations of wind characteristics to plan sites and designs for energy-producing wind turbines, climatic effects from energy developments, modeling and field observations of wind dispersion characteristics for pollution control, and meteorological forecasting. He has made significant research contributions in the field of boundary layer dispersion. In Operation Green Glow, an experimental release of radionuclides in the atmosphere, he measured the dispersion characteristics of the atmosphere with respect to the particles. This was the largest atmospheric diffusion experiment ever conducted, and information from this test helped Hanford scientists assess the impact of placing nuclear power plants in climates of differing type and terrain. Elderkin was also the project manager for the Wind Characteristics Program Element of the Federal Wind Energy Program, for which he evaluated wind characteristics to plan sites and help design energy-producing wind turbines (Elderkin and Fuquay 1965).

JAKE HALES - HANFORD SITE 1962-1991

Jake Hales is an atmospheric chemist who came to the Hanford Site in 1962. He quickly rose to senior scientist and Manager and Director of Atmospheric and Earth Science Programs. His research interest has been in the application of chemical engineering to environmental sciences, atmospheric sciences in particular. He has focused on particle transport and reaction-rate phenomena in his research. Hales research at PNNL includes the Multistate Atmospheric Power Production Pollutant Studies, for which he performed fundamental research on the removal of material by clouds, which is later released as rain. This acid rain is the wet deposition of sulfate particulate matter. He performed theoretical modeling, along with field observations, to determine how removal of particulate matter, such as sulfates and nitrogen oxides, affect rain. Hales created the Pluvious Model, created to model storm, cloud and atmospheric chemistry at small scales. From this model, the GChM-Global Chemistry Model grew, which modeled the same parameters but on a global scale. This model was designed for multi-day simulations over a wide range of spatial scales to solve air pollution problems.

As a result of public concerns about these releases causing adverse health effects, the exposures from the Green Run as well as other releases were estimated by the Hanford Environmental Dose Reconstruction Project, which began in 1988 with the work performed by Battelle under the supervision of the U.S. Centers for Disease Control and Prevention. The U.S. Centers for Disease Control and Prevention also funded the follow-on study, the Hanford Thyroid Disease Study, in 1989. The mission of the Hanford Thyroid Disease Study was to determine whether an increased incidence of thyroid cancers existed in the populations living at or around Hanford in the 1940s and 1950s. The results of these studies are not covered within this document, but information can be obtained from the U.S. Department of Energy Public Reading Room located in Richland, Washington (http://reading-room.pnl.gov) and the Hanford Site web page (http://www.hanford.gov).

Public concerns about the hazards of atmospheric nuclear fallout testing and the siting of proposed nuclear facilities were mounting between the 1950s and mid 1970s. This prompted researchers at Hanford to conduct a large number of diffusion grid experiments involving surface and elevated releases of radioactive tracers. The first and best-known group of experiments was conducted in the summer of 1959 and called Operation Green Glow. It consisted of 28 releases of fluorescent pigment during relatively stable night-time atmospheric conditions (Nickola et al. 1983; see also sidebar box on Elderkin). In 1962 and 1963, Hanford intentionally released small amounts of iodine 131 from the REDOX Plant to study the dispersion of radioactive iodine into the air and soil. During the emission, plume trajectories were plotted and samples collected at several altitudes and up to distances 50 miles away. In addition, vegetation and milk samples were collected. This study was designed to evaluate the spread and behavior of iodine released into the atmosphere and provide data to estimate the hazards potentially associated with weapons testing or nuclear fallout. To obtain data on inhalation uptake, two Hanford employees and several beagles stood directly in the path of the release (Gamertsfelder 1963, DOE 1995c).

During the 1970s experiments were conducted to determine whether radioactive particles from various study sites on the Hanford Site were resuspended and transported by wind. Interrelationships between wind speed, direction, airborne soil, and radioactivity levels on airborne particles indicated that airborne concentrations increased with wind speed, the weathering half-life was greater than previously reported, and concentration rates were more concentrated than fallout levels. These studies were useful for determining the extent of cleanup operations, i.e., soil cover-up, areas to clean up first, and modeling concentrations for down wind and offsite. The meteorology and atmospherics group continues to provide information on weather forecasts, preparing climatological summaries for the Hanford region, and observe and record weather conditions.

Just as researchers were concerned with atmospheric releases of radioactive materials, Hanford scientists were also concerned about radiation and heat effects on the Columbia River and plants, algae, insects, fish, and introduction to the food chain. These concerns led to the development of comprehensive research programs focusing on applied fish studies, radioactivity field studies, studies on reactor effluents, and environmental and biological monitoring.

APPLIED FISH STUDIES

Initially very little was known about the interactions of ionizing radiation and the immediate environment, therefore, it was essential to monitor the safety of reactor operations through a number of scientific studies. The secretive nature of activities at the Hanford Site necessitated that initial investigations occur offsite. In August 1943, the Fisheries Department at the University of Washington was contracted to undertake special studies on the effects of radioactivity on aquatic organisms, especially fish. The Fisheries Department soon thereafter organized as the Applied Fisheries Laboratory and became an active component of Hanford research. Figure 2-7.2 shows early researchers at the Applied Fisheries Laboratory, circa 1944 (Becker 1990, p. 63).

Figure 2-7.2. *Early Researchers at the Applied Fisheries Laboratory Around 1944*

Initially the Applied Fisheries Laboratory used x-rays to study the effects of radiation on fish. However, those involved in the project believed the specific isotopes involved in reactor operation had to be studied because the isotopes were flushed into the Columbia River, thereby, affecting the fish (Becker 1990). As a result, Du Pont opened a small onsite facility in 1945 in the 100-F Area, the Aquatic Biological Laboratory. For more information on the Aquatic Biological Laboratory, see the 108F Building in Appendix B on the Internet.

The results of the few classified studies the Applied Fisheries Laboratory conducted between 1943-1945 were not published until 1947-1948 (Becker 1990, Bonham et al. 1948, Welander et al. 1948). The Applied Fisheries Laboratory connection with the Manhattan Project was acknowledged after World War II when the group was renamed the Laboratory of Radiation Biology to better reflect their expanding line of investigation (Becker 1990). Later studies involving the Columbia River and its organisms were carried out within the reactor effluent program, biological monitoring, and radioactivity field studies.

Radioactivity Field Studies and Reactor Effluent Studies

Radioactive material releases to the Columbia River came primarily from the Hanford Site's first eight production reactors. These reactors, called single-pass or once-through reactors, used river water for cooling. Once circulated through the reactors, hot effluent water was discharged into cooling ponds and eventually returned to the river. The result was a release of fission products and other radioactive materials into the river. In concurrence with the applied fish studies, collection of Columbia River water began in 1944. However, routine analysis of radioactivity in river organisms began in 1946. From these studies, researchers learned that the amounts and distribution of radioactivity in the Columbia River were controlled by complex ecological factors including seasonal variations in aquatic communities, food chain relationships, and river temperature and flow. The studies on artificial radioactivity and river ecology were interrelated and led to the development of the scientific field known as radioecology (Becker 1990).

Controlled reactor effluent studies were related to both the applied fish and radioactivity field studies. All three were concerned with the impact radioactive isotopes would have on the area's main source of water used for drinking and agricultural purposes in addition to cooling the reactors. The most effective way to examine the biological effects of reactor cooling water effluent was in laboratory experiments. Fish were reared in tanks filled with varying dilutions of reactor effluent. The objective of these studies was to determine what conditions (radioactivity, chemical toxicity, temperature, or any combination of factors) caused adverse effects on the fish. Effects were evaluated by comparing mortality and growth rates between control and exposed groups of fish (Becker 1990).

Other field studies involving use of Columbia River water included use as irrigation on controlled vegetable plots. The data were used to predict the relative hazard of different isotopes associated with Hanford operations. Migratory fish were also monitored to study how radionuclides would disperse from the Columbia to the Yakima and Snake rivers (Kornberg 1964).

Environmental and Biological Monitoring

First implemented in 1943, environmental monitoring was essential to secure the health and safety of Hanford workers and area residents. Detection instruments monitored workers, residents, and the environment for radiation (see previous sub-section on Detecting Radiation). In view of what we know today, unvoiced concerns for the health and welfare of Richland residents and Hanford Site employees were masked with consumption and behavioral recommendations by the Medical Department (Gerber 1992a, pp. 72-73). For instance, the use of iodized salt was encouraged because animal experiments in 1945 suggested inert iodine reduced thyroid uptake of carrier-free radioiodine. In mid-1947, atmospheric tests determined airborne radioactive contamination deposited readily on sagebrush. The Richland Public Health Section then advised residents to remove them on the premise that they aggravated allergies and harbored ticks. And in 1949, traditional hunting areas near the Hanford Site were closed due to the discovery of high radioactivity levels of iodine-131 in game animals.

The rush to successfully complete construction and start plutonium production at the Hanford Site necessitated minimizing potential health and safety problems. Consequently, public suggestions were the only way to alert residents and employees to potential health concerns at the Hanford Site without causing too much alarm and panic. In the early phases of environmental monitoring and radiation protection, it was often unclear what acceptable tolerance doses were and what the limits should be. Initial studies at the Hanford Site helped establish these guidelines and studies have continued to the present day. For more information on tolerance doses and limits, see the Health and Safety Section.

Monitoring of various species has been of primary importance at the Hanford Site. Transmission of radioactive materials through biological chains revealed information about radionuclide transfer. Controlled laboratory experiments on animals fed or injected with radioactive compounds aided the development of exposure levels for humans and provided a baseline for comparing anomalies of wildlife on the Hanford Site. Field studies on various biological species (plant and animal) have contributed to basic knowledge of the processes of radionuclide uptake and transport (GE 1951c, Kornberg 1964, Pearce 1967). Area livestock were also examined and though positive but low thyroid readings were found in almost all animals, researchers felt comfortable in stating that it was very "unlikely that animals or persons consuming milk and meat products grown in the vicinity of Hanford were in any case damaged" (Herde quoted in Stannard 1988, p. 762).

Radiobiology

When the production plants at the Hanford Site and other areas started operations in the 1940s, scientists did not understand well the effects that radiation could have on workers, the public, or the environment. The programs that began initially with the applied fish studies expanded over the years to include aquatic life studies, plant life studies, ranch and wildlife studies, the development of an experimental animal farm, human radiation studies, therapy with radioactive materials, and general biology (Parker 1948b, GE 1951c). Stannard (1988) summarizes the range of radiobiological research across the weapons complex and at the Hanford Site, identifying three major areas at the Hanford Site:

- Fish studies (described in a previous sub-section) to understand the biological effects of reactor effluents released to the Columbia River on indigenous fish.
- Large and small animal studies to introduce radioisotopes into living tissue of animals such as sheep, pigs, dogs, and rats, and study them over time to identify and measure effects. Inhalation, inoculation, ingestion, and adsorption methods were used to introduce radioisotopes such as iodine-131, strontium-90, cesium-137, and plutonium and uranium isotopes into the animals.
- Radioecology studies to understand the effects of soil containing radionuclides. Greenhouses and garden plots were maintained to grow cereal grains, alfalfa, and other crops in soil containing controlled amounts of strontium-90 and cesium-137.

The Radiobiology Program at the Hanford Site along with the parallel programs at the Oak Ridge Reservation in Tennessee, and Brookhaven, New York, played an important role in the nation's efforts to understand the impact of ionizing radiation on living tissues (Gerber 1993b, pp. 172-199).

Three of the central researchers of radiobiology at the Hanford Site were Herbert M. Parker, William Bair, and Ethel Gilbert (see sidebar box).

> ***"Researchers at the Hanford Site conducted pioneering radiobiological studies during these years [1945-1965]. They examined the effects of I-131 [iodine-131] on sheep, the biomedical effects of tritium and plutonium, and the reactions of plant life to radiation, and they participated in the quest for radiation therapies. Hanford's chief health physicist, Dr. Herbert M. Parker, also helped to establish tolerance doses for various forms of exposure to radiation. Additionally, the Hanford Site played a seminal role in tracking and studying the effects of fallout, from distant atomic bomb tests, on the Pacific Northwest and on other regions, including the South Pacific and Alaska. As information developed about the biomedical effects of ionizing radiation in the two decades after the founding of the Hanford Plant, researchers in chemistry, physics, medicine, and agriculture, as well as members of the public who read popular scientific journals, came to recognize the magnitude and intransigence of the effects of radioactivity on living tissue,"*** **- Gerber 1993b, p. 172**

Inhalation (Pulmonary Radiotoxicology) Studies

Inhalation experiments at the Hanford Site were a major area of research within the general Radiobiology Program. They began by placing mice in the atmosphere of a chemical processing plant expected to contain radioactive particles. In the early 1950s, the inhalation program was more formally organized under the title Pharmacology Operation. The program then concentrated on introducing radioactive elements to animals via intratracheal instillation (Stannard 1988). Hanford researchers reported the first clear-cut demonstration of the development of lung cancer from plutonium in 1955 (GE 1956b). To further address health and safety concerns regarding worker inhalation of radioactive particles and

HERBERT M. PARKER - Hanford Site 1944-1984

Herbert M. Parker was a medical physicist who started his career in Enrico Fermi's Metallurgical Lab. Before coming to Hanford, he researched the new and unstudied field of the effects of beta-particle radiation in fission products. One of Parker's earliest concerns was the effect of inhaled radiation. In the early days of the Hanford Site, he was the first chief health physicist and Head of the Health Instruments Section. Parker was responsible for expanding what had been a primarily monitoring and control operation into a world-renowned radiobiology and health physics research program. In the days of the General Electric Company, Parker was made Director of the Hanford Laboratories. He was one of the leading researchers into dilemmas of radon lung dosimetry and modeling for dosimetry (measuring the number of roentgens absorbed due to exposure to radiation). He wrote the earliest summary on the probable mechanisms of the biological action of beta particles, assisted in the development of the first standards for maximum permissible plutonium concentration levels in biological tissue, and subsequently devised standard units of ionizing radiation dose, first known as the rep or roentgen equivalent physical. Parker was a member of the National Academy of Engineering, and a U.S. representative for multiple national and international committees on radiation standards, including the first Atoms for Peace Conference in 1955 (Parker 1977 and Parker et al. 1986).

WILLIAM J. BAIR - Hanford Site 1954-present

Bill Bair was the first in the world to earn a Ph.D. in the brand new field of Radiation Biology from the University of Rochester in 1954. He was a health physicist, who spent his entire career at the Hanford Site, first as a staff scientist and ultimately as the manager of the Life Sciences Program, studying the respiratory and non-respiratory effects of toxins (radioactive and non-radioactive) on biological organisms. Bair developed the inhalation toxicology program at the Hanford Site into a major center for all aspects of inhalation toxicology. Bair designed and developed the means for aerosolizing radioactive materials safely by devising exposure chambers, aerosol generators, measuring systems, and administration devices to administer toxic aerosols to test animals. He studied the effects of the toxins on the animals, including the development of tumors and safe means of removing cancerous lumps, and was the first person to demonstrate the production of a lung tumor by plutonium. He also studied the relative toxicity of plutonium isotopes, including their role as cancer agents. The results of this study helped deduce the relative long-term risk associated with each isotope. His research led to devising new admissible radiation standards for the Natural Resources Defense Council. In addition to radionuclide research, his studies focused on the role of toxic agents other than radon and its associated daughter products in animal research, including cigarette smoke, diesel exhaust, and uranium ore dust (Bair 1965, 1988; Thompson and Bair 1972).

ETHEL S. GILBERT - Hanford Site 1973-1994

Ethel Gilbert was a senior scientist in radiobiology and epidemiology. Her career has focused on the health effects of high level and low level radiation on humans, including modeling cancer risk from radiation. While at the Hanford Site, she conducted an analysis of health data and mortality data from 44,500 Hanford Workers from 1944-1978 and studied the effects on survivors of the 1945 atomic bomb dropped on Hiroshima. During Gilbert's career, she also developed models for estimating cancer risks, including a model on risk in the event of a nuclear disaster and the risk of lung tumors from toxic substances (Gilbert and Marks 1979, Gilbert and Sever, 1987).

determine safety guidelines, controlled research experiments were performed on mice and later involved beagles, sheep, and swine bred and raised in laboratory facilities. These studies aided investigations of levels of toxicity in various organs and the blood, concentrated deposition throughout the body, and other defects on the organism (Pearce 1967). Studies on the inhalation and ingestion of iodine in laboratory animals concluded that iodine was usually rapidly absorbed and transported, quickly excreted, and primarily deposited in the thyroid (Stannard 1988).

During the 1960s, the Pharmacology Group concentrated most of its research on the inhalation toxicology of plutonium. The ultimate concern was its long-term toxicity on workers, which eventually led to other studies extending into the 70s and 80s on the inhalation of uranium ore dust, diesel exhaust fumes, and cigarette smoke. The inhalation toxicology program also grew in size to accommodate studies on transplutonics, plutonium-sodium aerosols, and radioisotope toxicology.

Environmental Research

During the creation of the Hanford Site, the formation of a large buffer zone around the central facilities was imperative for security and public safety. As a result, several portions of the Hanford Site have remained relatively undisturbed by human activities. Approximately 4 percent of the site's 560 square miles has been used to produce plutonium and contains waste treatment and research facilities.

> **A reserve was established to *"Preserve portions of vegetation types that once covered a great expanse of the West… ALE [Arid Lands Ecology Reserve] is intended to maintain significantly large remnants of the native plant and animal communities… Provide an undisturbed system where ecologists can examine environmental questions… Provide an area large enough that ecologists can conduct controlled manipulations without destroying the integrity of the natural system… Provide field study areas for the scientific and educational community, particularly graduate students in the environmental sciences."* - O'Farrell 1973**

In 1967 the Atomic Energy Commission set aside 120 square miles of shrub-steppe land at the Hanford Site to preserve a natural ecosystem for research and educational use (Hinds and Rogers 1991). This outdoor laboratory, originally called the Arid Lands Ecology Reserve, is managed by the Pacific Northwest National Laboratory . The Arid Lands Ecology Reserve was later named after Richard E. Fitzner, and Lester E. Eberhardt, who had spent many years observing animals at the reserve before they died in a plane crash while studying wildlife near Yakima, Washington in 1992. The Fitzner-Eberhardt Arid Lands Ecology Reserve has remained primarily undisturbed and fits the classification used by federal land management agencies to designate lands on which various natural features are preserved for research and educational purposes (PNL 1993).

In 1977, the Hanford Site was designated a National Environmental Research Park by the U.S. Department of Energy. William H. Rickard was the driving force behind the establishment of the park (see sidebar box). The Hanford National Environmental Research Park, one of seven national environmental research parks (see Figure 2-7.3), includes (see Figure 2-7.4):

- Fitzner-Eberhardt Arid Lands Ecology Reserve (formerly the Arid Lands Ecology Reserve)
- Industrial zone of the Hanford Site
- Buffer zones on the opposite shore of the Columbia River – the U.S. Department of the Interior's Saddle Mountain National Wildlife Refuge and the Washington State Wahluke Wildlife Area.

The national environmental research park concept is an outgrowth of the National Environmental Policy Act of 1969 and the public desire for a clean environment. The Hanford National Environmental Research Park provides the foundation for present and future studies in the areas of environmental restoration, waste and land management, and the maintenance of plant and animal species. A vast variety of studies have been completed at Fitzner-Eberhardt Arid Lands

WILLIAM H. RICKARD - Hanford 1960-present

William Rickard is a terrestrial ecologist whose research has centered around field sampling to measure primary productivity, soil-plant mineral relations and man-imposed perturbations, especially cattle grazing, severe soil disturbances, and airborne chemical contaminants in the shrub-steppe desert of the Columbia Basin. As a senior staff scientist, he has dedicated his life to the long-term monitoring of vegetation and wildlife. He joined Hanford's young terrestrial ecology program to study the effects of radioactive fallout on the environment, and to do a pre- and post-shot assessment of the proposed Project Chariot, which was a plan to excavate a harbor in Alaska with a nuclear device. His in-depth research has included monitoring the effects of fallout and soil contamination on the terrestrial systems, including root uptake and the effects on the transfer of radionuclides through the food chain. Rickard's greatest contribution to the field of ecology, in his estimation, is his role in establishing the Hanford Site as a National Environmental Research Park (Rickard 1972, 1979, 1988; Vaughan and Rickard 1977; Sackschewsky et al. 1992).

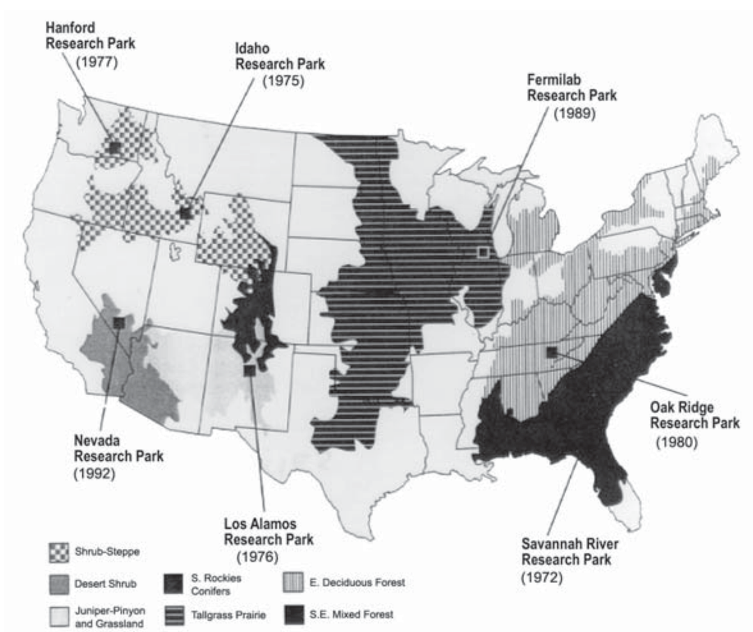

Figure 2-7.3. *Seven National Environmental Research Parks Designated by the U.S. Department of Energy*

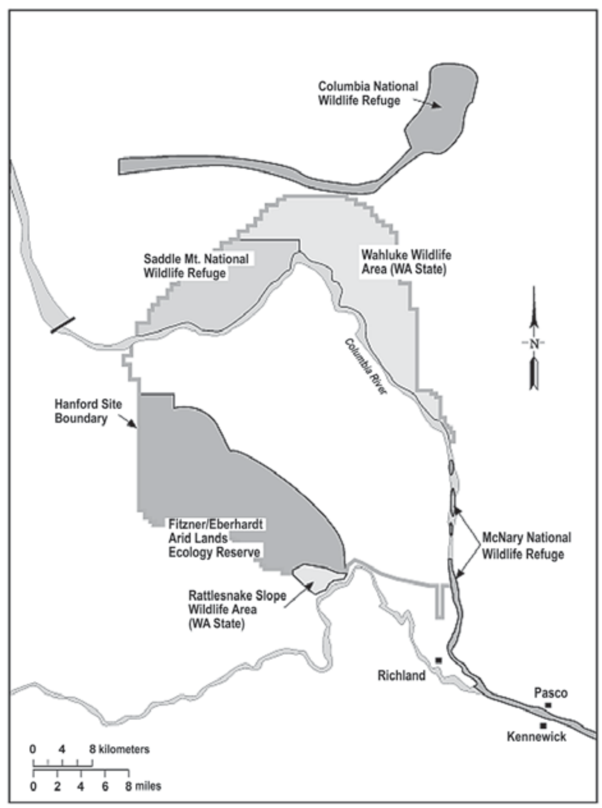

Figure 2-7.4. *Hanford National Environmental Research Park*

Ecology Reserve, including many in the disciplines of geology, microclimatology, ecology, botany, soil science, and animal ecology. As of 1990, over 40 species of mammals, 187 species of birds, 3 species of amphibians, and 9 species of reptiles had been documented, some of which spend part or all of their life-cycle on the Reserve (Fitzner and Gray 1991).

Nuclear Production

Following World War II, the Hanford Site played an increasing role in R&D activities in response to demands from the government for greater weapons production and demands from private industry to commercialize nuclear energy. As nuclear technology expanded and became better understood, the government increased its research on means of controlling the atom, from the mining of uranium to the safe disposal of spent fuel.

Much of the R&D initially related to plutonium production are found in the respective sections on Fuel Manufacturing (Section 2), Reactor Operations (Section 3), Chemical Separations (Section 4), and Plutonium Finishing (Section 5). This section focuses on R&D activities that extended beyond the boundaries of Hanford plutonium production.

By the early 1950s, nuclear technology was in a growth mode. Although no technology beyond weapons production had yet been developed, scientists were eager to explore the atomic energy and its place in every day living. The utility industry was preparing for its arrival, universities were starting programs to train students, and politicians were pressuring the Atomic Energy Commission to begin transferring the technology (Hewlett and Holl 1989b, American Nuclear Society 1992).

By the mid-1950s, the nation, especially the government, faced a great need for nuclear expertise to fulfill its growing list of responsibilities. The Hanford Site with its staff and facilities represented one of the major centers of nuclear technology in the world, and the only national resource with seasoned reactor operating experience. As a result, much R&D work came to the Hanford Site. One of the main nuclear researchers was Spencer H. Bush (see sidebar box). An indication of the value of this expertise is demonstrated by the number of Hanford staff who GE took with it when it left the Hanford Site to develop its commercial business.

SPENCER H. BUSH - Hanford Site 1953-present

Spencer Bush began his career at the Hanford Site. Coming to the Hanford Site was natural for him. He had been involved in the Manhattan Project at the Los Alamos Laboratory while an enlisted man. He was the driver of the truck that delivered the bomb from Los Alamos to the Alamogordo Bombing Range, New Mexico for the world's first atomic explosion, the Trinity test in 1945. His interest in nuclear technology led him to the Hanford Site after finishing his Ph.D. in 1953. He first contributed to Hanford research as a senior staff scientist, Physical Metallurgy and Fuel Fabrication Program and later as a Consultant to PNNL. His main research contributions have been in the fields of physical and mechanical metallurgy of nuclear materials and reactor safety and more efficient reactor and fuel design. He has studied and solved problems concerning the effects of irradiation on metal components, and stress corrosion on pipes, and subsequent cracking. His research has also considered the effect of fabrication variables on properties of zirconium alloys, irradiation effects in uranium alloys and reactor structural materials and stress corrosion, all aimed at improving safety and efficiency of reactors, specifically N Reactor (Bush 1965).

Nuclear research at the Hanford Site that went beyond the immediate production needs focused on:

- Fuel Performance
- Reactor Performance
- Nuclear Waste Management
  - Waste forms
  - Interim storage
  - Long-term storage
  - Transportation
  - Regulations
  - Environmental Restoration

- Policy and Regulatory Analysis
- Environmental Restoration

Fuel Performance

Hanford staff gained considerable expertise in manufacturing fuel, assessing fuel failures, and improving fuel performance. Hanford reactors used metallic fuel, recognized early on as an inefficient form of uranium compared to oxide fuel blends when used to produce energy. Much of this work was in response to fuel failures, which increased as the Hanford Site increased the performance of the reactors.

When it came time to design the advanced K Reactors at Hanford, much work went into exploring alternatives for the standard Hanford fuel assembly. Again, when the N Reactor was being designed, a substantial amount of R&D went into the manufacturing of fuel elements using a coextrusion process (see the Fuel Manufacturing Section). All of this work established Hanford staff as a resource for nuclear fuel technology.

Because of Hanford's fuel expertise, the Atomic Energy Commission chose the Hanford Site to develop methods to increase the efficiency of uranium fuel by creating oxide fuel blends. Hanford's expertise relative to uranium fuel was limited to metallic fuel, conducive for producing weapons grade plutonium but not efficient for producing energy. Nevertheless, in the mid-1950s, few had the operating experience of the Hanford Site. Thus, the Hanford Site was chosen for a large fuels diversification program known as the Plutonium Fuels Utilization Program begun under President Eisenhower's Atoms for Peace initiative. The hallmark of this program was the Plutonium Recycle Test Reactor, which was located in the 309 Building (Purcell 1966). Tests on a variety of powdered and pelletized fuels continued throughout the 1960s using plutonium oxide blended with uranium oxide and other metallic oxides. For information on the 309 Building, see the Expanded Historic Property Inventory Form in Appendix B on the Internet.

As a result of this and other Hanford research on the performance of fuel, nuclear power plants began using solid, ceramic-like pellets of enriched uranium, slightly larger than pencil erasers, stacked atop each other and sealed in strong metal tubes, called fuel rods. By the early 1970s, Hanford fuels researchers were called upon to work on breeder fuels. This included work at the Chalk River Reactor in Canada. And in 1986, Hanford fuels researchers were chosen to play a new role in a new space technology development program known as SP-100. The SP-100 nuclear reactor, designed by General Electric, would produce continuous power for at least 7 years. The 309 building was modified to prepare for this work, although the program fizzled after a few years.

Reactor Performance

By the mid 1960s, public interest in containing a reactor accident increased in large part due to suspicions about regulatory problems (such as the use of mill tailings for construction purposes), thermal pollution, radiation standards, environmental protection, and waste disposal. When the Atomic Energy Commission's reactor development studies were going on in the mid-1950s, Hanford staff were busy working on the K Reactors to address the Korean Expansion and did not play a substantive role in the various studies. The K Reactors had, however, despite the fact that they were still using the basic Hanford graphite moderator technology, introduced many new technological aspects, especially in the area of new materials, such as zirconium.

Following the construction of the K Reactors, considerable R&D went into the design of N Reactor, which was still a graphite reactor but incorporated many new elements of technology, such as enhanced core design, new fuel making technology, new materials, and a closed-loop system (DOE 1997a). See the Reactor Operations Section for more information on the design of the N Reactor. These developments attracted much attention from the rapidly emerging nuclear energy industry. N Reactor quickly became one of the world's best known, power-producing reactors. While everyone recognized the limitations of the core technology, it was the various elements of the N Reactor system that attracted interest – the piping, safety systems, fuel rupture detection system, and controls.

Hanford staff also did a variety of lattice testing for the design of different light-water-cooled reactors, including those at the Hanford Site. Tests were conducted in the Plutonium Recycle Critical Facility, also in the 309 Building, to determine which geometrical arrangement of fissionable materials would work best in a reactor. Spacing, fuel size, number of fuel elements, choice of material, and other factors all had benefits and drawbacks. The challenge to researchers was to determine which combination worked best. Much of this work was done under the auspices of the Nuclear Regulatory Commission for commercial companies such as Westinghouse Corporation, Babcock and Wilcox Corporation, and Combustion Engineering.

By the mid-1960s, interest in containing a reactor accident increased. The Atomic Energy Commission focused its attention on the emergency core cooling system. The thought was that if the emergency core cooling system was properly designed and constructed, the system would prevent the core from melting when overheated and contain any radioactive releases. Hanford staff were called upon to assist in this effort by conducting containment integrity experiments (Walker 1992).

An indication of Hanford's reactor development expertise is the contribution of the Hanford Site to the Nation's Breeder Reactor Program. The breeder reactor was a fast reactor, not requiring a moderator. Liquid metal, such as sodium, was used to control the heat generated during the reaction. The breeder technology was desirable because the reaction actually produced more plutonium than it used. Research into breeder reactors began in the 1950s and was pursued by the United States, United Soviet Socialist Republic, France, the United Kingdom, and Japan. The Clinch River Breeder Reactor Project in the United States built a prototype breeder. The Hanford Site supported the Clinch River Project in a variety of ways.

As a result of the Clinch River Breeder Reactor Project, the U.S. Government decided to build a full scale breeder reactor. The Hanford Site was chosen, largely though the efforts of its powerful Senators, Senators Magnuson and Jackson. The Atomic Energy Commission commissioned Battelle to start designing the new breeder reactor known as the Fast Flux Test Facility in the late 1960s. Westinghouse Corporation won the contract to both construct and operate the Fast Flux Test Facility and with that approximately 800 R&D staff who had been working on the design for Battelle transferred to Westinghouse. Construction began in 1970, and the Fast Flux Test Facility began operations in 1980.

"Fast flux" means the neutrons move faster in a sodium-cooled reactor than they would if the reactor were cooled with water (WHC 1994). Heat was removed from the reactor by circulation of liquid sodium through three primary loops including primary pumps, piping, and intermediate heat exchangers, all located within the containment building housing the reactor.

The Fast Flux Test Facility was designed specifically to test the irradiation of fuels and materials. Reactor activities were later expanded to include long-term testing and evaluation of reactor components and systems, fusion power materials, passive safety systems as well as the production medical isotopes and research on space power systems (Mayancsik 1988). In 1984, the future of the facility became uncertain. The U.S. Government abandoned the program because of cost over runs, design failures, a vote by the U.S. Congress, and the belief it could undermine non-proliferation treaties.

In the late 1960s, PNNL researchers also worked on how to derive nuclear power. Much of this R&D was funded through the electric power industry consortium known as the Electric Power Research Institute (EPRI). EPRI was created in 1965 to address an increasing concern over electric power capability. The great northeastern blackout of 1965 exposed serious vulnerabilities in the nation's electricity supply system. The Middle East war in 1967 increased awareness of the dangers of relying on foreign sources for energy sources, such as oil. The National Environmental Policy Act of 1969 kicked off decades of environmental legislation that would challenge utilities' scientific and technical capabilities. These and related issues led many to question the ability of the existing energy infrastructure.

In response, the industry formed a collaborative science and technology organization to serve the entire power industry from energy conversion to end use. EPRI began offering scientific expertise and innovative technology to help its industry partners increase efficiency and prepare for the future. U.S. electric utilities established EPRI as a nonprofit membership corporation to manage a national research program on behalf of its funders, the industry, and society. In forming one of the first industry-wide research consortia, electric utilities pioneered the concept of pooling their resources for maximum benefit.

EPRI funded an enormous amount of R&D over the years, utilizing R&D organizations such as the Pacific Northwest National Laboratory. Researchers developed computer models and designed changes to increase the efficiency of cooling towers used by the nuclear power industry.

Nuclear Waste Management

Managing the waste created by nuclear facilities was a consideration from the beginning. Although low-level, liquid radioactive wastes were originally disposed of directly in the ground or in open ditches, they were believed to be temporary holding areas until safer and more effective means of disposal could be developed. High level radioactive waste was stored in underground tanks, and low level radioactive waste was disposed of in the soil, much of which would not be permitted by today's regulations. Little in the way of R&D efforts were expended at the Hanford Site during the first few decades. The means of managing waste were considered effective, and little pressure was applied to improve methods. Nuclear regulation began to intensify in the 1960s, though these new measures tended to focus on reactor siting and performance issues (Walker 1992).

As utilities started building and operating nuclear power plants in the 1970s and spent fuel began piling up, the government recognized the need to address the long-term management of spent nuclear fuel. The spent nuclear fuel assemblies, which were highly radioactive from the fission process, had to be isolated from the environment for long periods of time. Radionuclides in spent fuel assemblies have half-lives ranging from hours to millions of years. Ten half-lives must lapse for the radiation to be deemed safe by reaching acceptable levels.

The Nuclear Waste Policy Act of 1982 established the Office of Civilian Radioactive Waste Management within the U.S. Department of Energy to develop, construct, and operate a system for spent nuclear fuel and high level radioactive waste disposal. This included a permanent geologic repository, an interim storage capability, and a transportation system.

Scientists and engineers, some of them from the Hanford Site, had studied many options over the years for disposing of spent fuel. These options included leaving the waste at the reactor sites, burying it in the ocean floor or a deep geologic repository, putting it in polar ice sheets, and rocketing it into outer space. Based on a final Environmental Impact Statement prepared in 1980 that evaluated all of these options, deep underground geologic disposal was determined to be the safest solution (DOE 1980). The Nuclear Waste Policy Act established a specific funding mechanism for developing the waste disposal system, the Nuclear Waste Fund. This mechanism included collecting funds from those who used the electricity produced by nuclear reactors rather than the general taxpayer.

In the search for a site for the permanent repository, the Office of Civilian Radioactive Waste Management had initially conducted a national search for a potential site. Eventually the agency chose nine sites to be studied in six different states. President Ronald Reagan approved three sites from a candidate list of five for more detailed study. These potential locations for permanent repositories for spent nuclear fuel and high level radioactive waste were the Hanford Site, Deaf Smith County in Texas, and Yucca Mountain in Nevada.

To evaluate the Hanford Site for a long-term waste storage repository, the Basalt Waste Isolation Project was initiated. The Hanford Site was chosen for its 15,000 feet of basalt, believed to be viable for a geological repository. The Basalt Waste Isolation Project generated an enormous amount of R&D at the Hanford Site in the areas of site characterization and deep surface repository engineering. The project ended December 1987 when Congress amended the Nuclear Waste Policy Act and directed the U.S. Department of Energy to study only one site, Yucca Mountain, Nevada, to determine whether it was a suitable site for a repository.

The 1987 Amendments Act also authorized the Secretary of Energy to site a Monitored Retrievable Storage facility (DOE 1981b, 1983). This facility differed from the geologic repository in that it was an above-ground facility that would store a limited amount of spent nuclear fuel temporarily before sending it to a permanent repository. Hanford researchers, in this case primarily those at the Pacific Northwest National Laboratory, were very involved in the design work, workforce analysis, and siting requirements for the Monitored Retrievable Storage facility. The temporary storage method used by utilities was to place fuel in large pools of water contained in steel-lined concrete basins. Rather than using water for the Monitored Retrievable Storage facility, spent nuclear fuel assemblies would be stored in a dry environment, above-ground, using heavy containers or casks made of steel and/or concrete. Casks would be either placed upright on concrete pads or stored horizontally in metal canisters in concrete bunkers. The advantage of dry storage was a more stable environment with lower maintenance costs. Like pool storage, dry storage was not intended to be a permanent solution. However, funding to build the Monitored Retrievable Storage facility never materialized.

The Nuclear Waste Policy Act, as amended, also included requirements for spent nuclear fuel and high level radioactive waste to be transported in containers certified by the Nuclear Regulatory Commission. To safely and efficiently move radioactive waste around the country, PNNL researchers helped develop special containers for highway and rail transport. Each shipping container was designed to maintain its integrity under normal transportation conditions and during hypothetical accident conditions. The designs had to demonstrate protection against radiological release to the environment under the following hypothetical accident conditions:

- A 9 meter (30-foot) free fall on to an unyielding surface
- A puncture test allowing the container to free-fall 1 meter (40 inches) onto a steel rod 15 centimeters (6 inches) in diameter
- A 30-minute, all-engulfing fire at 800 degrees Celsius (1475 degrees Fahrenheit)
- An 8-hour immersion under 0.9 meter (3 feet) of water

Compliance with this sequential series of tests was demonstrated by computer modeling, scale-model or full-scale tests, parts of which were developed or evaluated by PNNL researchers.

In addition to the spent fuel from commercial reactors, the Nuclear Waste Policy Act also covered disposal of high level radioactive waste from the government's plutonium production facilities. In addition to storage and transportation issues, research had to address how to convert radioactive waste into a stable waste form, one capable of encapsulating the radionuclides for thousands of years. While Hanford researchers pursued a variety of stabilization technologies for high level and low level radioactive waste, vitrification technology was a major focus. Vitrification was an adaptation of melter technology developed in the glass making industry (Larson 1996).

Other waste-related R&D focused on the decommissioning of the Shippingport Reactor near Pittsburgh, Pennsylvania. Shippingport was one of the early demonstration reactors funded by the Atomic Energy Commission and private industry in the 1950s. The Shippingport plant was a pressurized water reactor design, based on Argonne National Laboratory's submarine reactor technology. This first commercial light water reactor plant operated from 1958-1982 (Beaver 1990).

Once operations at Shippingport ceased, the plant had to be decommissioned. Decommissioning this reactor was seen as an opportunity to learn much about reactor decommissioning, a process every reactor would eventually have to undergo. PNNL researchers assisted the U.S. Department of Energy in a wide range of studies surrounding materials performance, extent of contamination, cost models, and decontamination approaches.

Policy and Regulatory Analysis

As a result of concerns about the dangers of nuclear fallout and exposure to radiation in general, scientists, health professionals, and the public demanded standards for the protection of public health and safety. In 1954, the Atomic Energy Commission set up a regulatory program to do just that (Walker 1992). PNNL researchers assisted the Atomic Energy Commission for many years both in the development of regulations and in the implementation of policies and regulations. Such activities occurred for both the commercial and defense industries. This work continued under the Nuclear Regulatory Commission when the Atomic Energy Commission was split up in 1977.

Environmental Impact Statements were required under the National Environmental Policy Act. PNNL researchers were often called upon to supply scientific evidence for Environmental Impact Statements, such as those for the Hanford Defense Waste and the Commercial Wastes Environmental Impact Statements.

Hanford R&D staff also conducted similar work for the International Atomic Energy Agency. The International Atomic Energy Agency, created in 1957, is a specialized agency within the United Nations. Headquartered in Austria, the International Atomic Energy Agency serves as the world's central intergovernmental forum for scientific and technical co-operation in the nuclear field, and as the international inspector for the application of nuclear safeguards and verification measures covering civilian nuclear programs.

Environmental Restoration

As the Cold War started to wane, the U.S. Department of Energy came under increasing pressure to clean up its legacy wastes created during four decades of plutonium production. In 1986, the U.S. Department of Energy released 19,000 pages of documents on the history of the Hanford Site. From these, the public learned that radioactive and chemical wastes had been released in greater quantities than had been previously assumed. The issue of waste disposal became more prominent and once again, R&D staff were called upon to develop and evaluate cleanup methods and technologies that could assist with the cleanup efforts.

In situ vitrification is a good example of a technology developed by Hanford R&D staff, which may have widespread industrial applications. In 1988, Battelle Memorial Institute created Geosafe Corporation for the purposes of developing and commercializing advanced vitrification technologies for site remediation and waste treatment worldwide. The Corporation acquired rights to the U.S. Department of Energy's patent for the In Situ Vitrification technology, which was developed to treat TRU-contaminated soil in place.

Other Major Studies

Space nuclear system studies were designed to test the potential biological problems connected with the utilization of reactors or radionuclide power sources in space. The spread of radioactive contamination of operations in space could constitute a human hazard. These studies employed swine, rats, and dogs to explore possible dangers of inhaled and ingested particles. This research was an offshoot from the basic inhalation research program discussed above (PNL 1967a, Stannard 1988). In 1957, the Atomic Energy Commission launched proposals for the development of industrial uses of nuclear explosives, such as power generation by explosions, oil and mining operations, and large-scale earth excavations. Dubbed Project Plowshare, these proposals stemmed directly from the Atoms for Peace Program of 1953. Project Chariot, a program within Plowshare, was a planned excavation of a harbor near Cape Thompson, Alaska. Because the project site had not been thoroughly investigated before the planned work, bioenvironmental and public safety programs were initiated. The Hanford Biology Program contributed to three Project Chariot related environmental studies in Alaska: limnological investigations, ecology of terrestrial invertebrates, and radioecology of terrestrial and fresh water communities. The controversial Project Chariot program was suspended in the early 1960s due to public concerns about health hazards (O'Neill 1995, 1998). Other work in Alaska included studying the repercussions of radioactive nuclear fallout. A fairly large ecological program was started and food chain studies were undertaken for a number of years (GE 1960a, Stannard 1988).

Research and Development Facilities

The Hanford area most associated with R&D is the 300 Area. Although the 300 Area was originally known for fuel manufacturing, as R&D increased at the Hanford Site, research facilities were located in the 300 Area for three main reasons. The infrastructure was in place. The risk of accident was less than the areas where the reactors and chemical separations plants were in the 100 and 200 Areas, and the 300 Area was closer to residential areas for easier accessibility.

During the Cold War period, several test reactors and fuel fabrication pilot facilities in the 300 Area were used for non-military purposes. With the worldwide uranium supplies limited, research efforts were undertaken to develop and test alternate fuels. The most ambitious efforts were focused on the effectiveness of plutonium oxide and mixed oxide fuel blends. The Physical Constants Test Reactor and Thermal Test Reactor in the 305-B Building, the Plutonium Fabrication Pilot Plant, the Plutonium Recycle Test Reactor in the 309 Building, and the High Temperature Lattice Test Reactor in the 318 Building were constructed to develop and test alternate fuels as well as conduct other experimental testing programs.

During the period of considerable growth of the 300 Area in the early 1950s, many buildings and facilities were constructed under the Hanford Laboratories Operation Program for R&D activities. The most prominent developmental laboratories and shops included:

- 108-F Biology Laboratory – In 1949, the Biology Laboratory was completely remodeled to provide office and laboratory space for the Hanford Site Biology Program (DOE 1992b, DeFord 1993). The building was expanded in 1953 and again in 1962 to provide additional space for biological experiments. For over a quarter of a century, the building served as the main biology lab at the Hanford Site to study the effects of animals and plants. The Biology Program moved to the 337 Building in 1977, and the 108-F building was abandoned. In addition to the 108-F Laboratory, numerous other facilities, such as laboratories, barns, pens, pastures, gardens, and kennels, supported the Hanford Biology Program. For more information on the 108-F Biology Laboratory, see the Expanded Historic Property Inventory Form in Appendix B on the Internet.
- 305 Test Pilot/Hot Cell Verification Building – Built to house a small reactor that tested samples of the graphite, uranium and other materials used in essential Hanford operations. The 305 Reactor functioned as a quality assurance tool to house testing of samples of each lot of graphite, uranium, aluminum jacketing material, and other materials used in the large production reactors. The reactor was removed and buried in 1977-1978. For more information on the 305 Test Pilot/Hot Cell Verification Building, see the Expanded Historic Property Inventory Form in Appendix B on the Internet.
- 320 Low Level Radiochemistry Building – Completed in 1966, was virtually the last Hanford facility dedicated solely to national defense missions. The building's original mission was to house analytical chemistry services and provide plant support for work involving low level and non-radioactive samples. Twenty-two laboratories were located in the structure, including several devoted to wet chemistry, a large radiochemistry laboratory, an analytical R&D laboratory (Gerber 1993b, p. 52). Several pioneering techniques were researched in the building. These included radiometric techniques, new mass spectrometric techniques, combined atomic absorption analysis, and laser-based spectrometric techniques. The 320 Building currently provides a low level radiochemistry facility in which very sensitive radiochemical analysis, sample preparation, and methods development can be performed. For information on the 320 Low Level Radiochemistry Building, see the Historic Property Inventory Form in Appendix B on the Internet.
- 324 Waste Technology Engineering Laboratory – Completed in the mid-1960s as the Fuel Recycle Pilot Plant, designed partially to support PRTR operations by housing chemical reprocessing and metallurgical examination on the PRTR's fuel elements. As such, it was built as a dual facility with both radiochemical and radiometallurgical hot cells and laboratories. It also was designed to house the Waste Solidification Engineering Project, one of the first high level waste vitrification demonstration programs in the world (Gerber 1993b, pp. 48-50).
- 325 Radiochemistry Laboratory/Cerium Recovery Building – Completed in 1953, built to safely house and handle multi-curie level chemical development work with high activity substances. Initial building missions listed as high priorities included production support and process improvement (Gerber 1993b). The High Level Radiochemistry wing addition in 1959-1960 made the 325 Building the largest among the laboratories at the Hanford Site (Gerber 1992a). The addition, with its three larger hot cells, housed isotope research activities. For more information on the 325 Radiochemistry Laboratory/Cerium Recovery Building, see the Expanded Historic Property Inventory Form in Appendix B on the Internet.

- 326 Physics and Metallurgy Laboratory – Completed in 1953, designed to ensure the maintenance and improvement of reactor operations while developing new technologies for future reactors. The primary physics mission was to conduct the exponential reactor physics development work. The primary metallurgical mission was to examine reactor components and fuel elements to evaluate characteristics and performance (Gerber 1993b). For information on the 326 Physics and Metallurgy Laboratory, see the Expanded Historic Property Inventory Form in Appendix B on the Internet.
- 327 Post Irradiation Test Laboratory – Completed in 1953, built to house the examining and testing of irradiated materials, particularly fuel elements and fuel cladding materials from and for the production reactors, and of the effects of higher power levels of irradiation on new and different reactor structural materials. For information on the 327 Post Irradiation Test Laboratory, see the Expanded Historic Property Inventory Form in Appendix B on the Internet.
- 328 Mechanical Development Building (later called the Engineering Services and Safety Shop) – Built as a central shop to support the above laboratories. For information on the 328 Engineering Services and Safety Shop, see the Expanded Historic Property Inventory Form in Appendix B on the Internet.
- 329 Biophysics Laboratory – Built to support the pioneering environmental monitoring and bioassay programs that were developed at the Hanford Site during the 1940s and 1950s. The initial mission of the facility was to house the preparation and counting of radioactivity levels in air, vegetation, soil, wildlife, river and well water samples (Gerber 1993b, p. 24). Missions ranged from monitoring nuclear atmospheric fallout from nuclear bomb tests to fallout deposition studies on terrestrial organisms in Alaska to examinations of Mount St. Helens volcanic ash. For more information on the 329 Biophysics Laboratory, see the Expanded Historic Property Inventory Form in Appendix B on the Internet.
- 335 and 336 Sodium Test Facilities – Completed in 1968 and 1969, respectively, built to conduct sodium-related tests for the development of the Fast Flux Text Facility and cold sodium purification and characterization systems used in Fast Flux Text Facility studies. The sodium test loops were deactivated in 1977. Building 335 was known initially as the Fast Reactor Thermal Engineering Facility and Building 336 as the Core Segment Development Facility.
- 337 Technical Management Facility – Completed in five segments from 1970-1972, was the preeminent 300 Area structure built to support the development of the Fast Flux Text Facility. Originally, it housed engineering studies, including sodium loops and large mechanical mock-ups, and was a technical support facility for the mock-ups performed in the adjacent 337-B (high bay) Building. The 337-B Building initially housed R&D activities that included a core mechanical mock-up, a test bed for selected Fast Flux Text Facility components. For more information on the Technical Management Facility, see the Historic Property Inventory Form in Appendix B on the Internet.
- 427 Fuels and Materials Examination Facility – Completed in 1983 in the 400 Area, was a major addition to the breeder reactor technology program at the Hanford Site. Its function was to inspect irradiated fuels and materials from the Fast Flux Text Facility.
- Battelle Complex – When the Battelle Memorial Institute took over the Hanford Laboratories in 1965, it committed to build its own facilities on a square mile of land that it purchased at the southern end of the Hanford Site. The research complex was originally known in local lore as "Fort Courage," because "the building style and color reminded one a bit of something out of Beau Geste, and because the whole idea seemed wildly optimistic at that time" (Moore 1992, p. 122). Since this is a private facility, it is not being documented as the others are.

National and International Interactions of Hanford Research and Development Staff

Disseminating research results and sponsoring symposia and seminars are indicators of the interactions of the Hanford R&D staff with their national and international counterparts.

Publishing Research Results and Participating in Seminars and Conferences

The Hanford Site had a strong tradition of participating in regional, national, and international conferences. One of the most important conferences was the First Atoms for Peace Conference held in Geneva, Switzerland in 1955 (Fermi 1957). According to the list of participants, only Herbert Parker attended the conference from the Hanford Site (IC 1956). When the second conference occurred 2 years later, however, many Hanford staff attended and gave papers, especially in the area of potential health effects (IC 1958).

Participation in regional, national, and international conferences increased as national security concerns lessened over the years.

Sponsoring Seminars and Symposia

Beginning in 1962, the Hanford Laboratories and its successor, the Pacific Northwest National Laboratory, sponsored annual seminars and symposia on subjects directly related to research activities at the Hanford Site (Stannard 1988, p. 447). Before this time, seminars and symposia were not held on a regular basis. Table 2-7.3 shows between 1962-1990 symposia and seminars were held every year except in 1969 and 1982. Seminars may have been held in 1969 and 1982, but no references have been found to indicate as much. Both national and international scientists and researchers attended these meetings, which provided many opportunities for peer review. A significant number of symposia were held on radioisotope toxicology, a subject that contributed to Hanford's reputation as one of the prime centers for biological research in the subject (Stannard 1988, p. 450).

Table 2-7.3. *A Sampling of Symposia and Seminars Held at the Hanford Site, 1948-1990*

Year	Symposia and Seminars
1948	Fish and Fish Problems of the Hanford Reservation (Olson 1948)
1949	The Present Status of Polonium Tolerance Estimation (Hackett 1949)
1955	Symposium on the Iodine Problem (Hill 1955)
1962	Biology of the Transuranics (Thompson 1962)
1963	Foliar Sorption of I-131 by Plants: Biology of Radioiodine (Bustad 1964)
1964	Inhaled Radioactive Particles and Gases (Bair 1965)
1964	Biology of Radioiodine (Watson et al. 1964)
1965	Radiation and Terrestrial Ecosystems (Hungate 1965)
	Swine in Biomedical Research (Bustad and McClellan 1966)
1966	Symposium on Gastrointestinal Radiation Injury (Sullivan 1968)
1967	Diagnosis and Treatment of Deposited Radionuclides (Kornberg and Norwood 1968)
1968	Myeloproliferative Disorders of Animals and Man (Clarke et al. 1968)
1970	Pollution and Lung Biochemistry (Menzel 1970)
1971	Biological Implications of the Transuranium Elements (Thompson and Bair 1972)
1972	Radionuclide Carcinogenesis (PNL 1972a)
1973	Cell Cycle in Malignancy and Immunity (Hampton 1973)
1974	Radiation and the Lymphatic System (Ballou 1974)
1975	Biological Implications of Metals in the Environment (Drucker and Wildung 1975)
1976	Pulmonary Macrophage and Epithelial Cells (Sanders 1976)
1977	Developmental Toxicology of Energy-Related Pollutants (Mahlum 1977)
1978	Biological Effects of Extremely Low Frequency Electromagnetic Fields (Phillips 1978)
1979	Pulmonary Toxicology of Respirable Particles (Sanders 1979)
1980	Coal Conversion and the Environment: Chemical, Biomedical, and Ecological Considerations (Mahlum et al. 1980)
1981	Biological Availability of Trace Metals (Wildung and Jenne 1981)
1983	Life Span Radiation Effects Studies in Animals: What Can They Tell Us? (Thompson and Mahaffey 1983)
1984	Interaction of Biological Systems with Static and ELF Electric and Magnetic Fields (Anderson et al. 1984)
1985	Health and Environmental Research on Complex Organic Mixtures (Gray 1985)
1986	Radiation Protection: A Look to the Future (Bair 1988)
1987	Modeling for Scaling to Man: Biology, Dosimetry, and Response (Mahaffey 1989)
1988	Multi-Level Health Effects Research: From Molecules to Man (Park and Pelroy 1989)
1989	Environmental Monitoring, Restoration, and Assessment: What Have We Learned? (Gray 1990)
1990	Indoor Radon and Lung Cancer: Reality or Myth? (Cross 1992)

Areas for Further Research

In the early years, the Hanford Site was the dominant client for the research staff. As the need for nuclear weapons subsided and other research needs arose, sites such as Hanford pursued diversification. Researchers found their knowledge of materials, physics, mathematics, the environment, etc. could be applied to new areas, particularly those in industry. In this regard, Hanford R&D underwent a fundamental shift from being a specialized research institution supporting a clear-cut national mission – nuclear weapons production – to a generalized research institution supporting a combination of national missions such as energy efficiency, economic competitiveness, environmental quality, and education. Government needs also changed as the government increasingly called on research staff not just to develop technology but to evaluate technologies, develop protocols, and provide independent oversight. Therefore, virtually limitless areas exist for future research of R&D activities at the Hanford Site and in relation to academia, other nuclear installations, and the history of science and technology in the United States.

- R&D activities at the Hanford Site have undergone a variety of changes during the past 50 years. In many fields, the history of basic research has gone undocumented and passed over in favor of the more lucrative commercial applications of applied research, project development, and process and product improvements. A thorough analysis and chronology of Hanford's basic research programs since the late 1940s should be undertaken in the future.
- With this in mind, oral interviews with pioneering researchers at the Hanford Site may also prove of interest to the general public and historians of science and technology.
- It would be of interest to document how national and international seminars and symposia may have impacted research ideas and design between researchers in academia, industry, and government.
- Were techniques and instruments developed at the Hanford Site applied in non-governmental settings?
- How have Hanford researchers influenced R&D in non-governmental settings? What patents resulted from research at the Hanford Site?
- The origins of the U.S. Department of Energy's national laboratory concept arose out of compelling national need because of the nuclear weapons race. In that regard, the concept of a nationalized R&D industry was successful, concerns about environmental and human health notwithstanding. In the absence of any emergency situations, is a nationalized R&D force effective?
- Were the R&D contributions to nuclear energy, energy conservation, addressing environmental and nuclear legacy waste problems commensurate with their costs?
- Are there alternative ways to structure a nationalized R&D group? How does working in a national laboratory differ from other R&D settings such as industry and higher education?
- Hanford's R&D budgets have not been made available to the public. When they are, it would be useful to evaluate how much money was spent on basic research versus applied R&D. These figures would also prove useful in compiling a comparative data set of R&D spent at other nuclear sites around the country.
- The use of humans in radiation experiments financed by the U.S. Department of Energy and its predecessor agencies remains a topic of considerable interest and controversy. To the authors' knowledge, not one source document exists detailing all of the human experiments performed at the Hanford Site or by Hanford researchers off-site. It would be beneficial to compile these data and conduct oral interviews with both the researchers and the human subjects. Many scheduled follow-up studies proposed by the U.S. Department of Energy were never conducted or were cancelled. More work is needed to understand how researchers and decision makers rationalized the use of human subjects and the possible long-term health consequences they may have experienced.
- Radiation detection programs at other national laboratories have been linked to research on important military applications such as nuclear warfare, detecting radiation that could compromise the functioning of nuclear submarines and detecting radiation on the nuclear battlefield. Were any of the results of human radiation programs or radiation detection programs at the Hanford Site used in these other studies? If so, how were the results applied?
- It would be of value to document the popular views held by area residents about R&D at Hanford. Did their knowledge about particular experiments with animals and occupational injuries influence their attitudes toward atomic energy and government installations in general? Did these views affect the types of research performed?

Biological and Ecological Research Projects at the Hanford Site, 1951-1990

Year	Biological and Ecological Research Projects (As Indicated by Annual Reports)
1951 (GE 1951b)	• **Biological Sciences:** radioactive isotope studies on aquatic organisms; mean activity density of iodine-131 in jack rabbits; duck exposure to pile effluent; tritium and tritium oxide absorption and retention studies on humans, rats, and plants; uptake of radioactive strontium, yttrium, cesium, and iodine in plants; plutonium fixation in rats; biological effectiveness of radiation in bacteria; pile effluent water toxicity to fish and bean plants; iodine-131 studies on sheep
1952 (GE 1952b, 1953c)	• **Aquatic Biology:** pile effluent monitoring with Silver salmon, Chinook salmon, Rainbow trout; algae growth in pile effluent • **Metabolism Studies:** plutonium and tritium absorption and deposition in rats and rabbits; percutaneous absorption of tritium oxide in man; absorption and translocation of various fission products in plants; chronic effects of pile effluent on plants; effects of radiation from various isotopes on the growth of algae • **Toxicology:** radioiodine in sheep to study growth, birth defects, tumors, etc.; removal of plutonium in dogs via sirconium salts • **Biological Services:** biological monitoring of goats, plants, wildlife and waterfowl, sheep, rabbits, and cadaver ashes • **Biological Sciences:** removal of radiophosphorus contaminant from water in an aquarium community; extended retention of Rainbow trout in dilute reactor effluent; effect of reactor effluent on young Silver salmon; chronic effects of pile effluent water on cereal plants; metabolism of tritium gas in the rat; long-term retention of tritium in the rat and sheep; metabolism of hydrogen isotopes by algae, rat metabolism of deuterium and tritium; plutonium absorption studies of the rat; intravenous effects of plutonium on the dog; radioactive elements in "Jangle" soil; absorption and translocation of fission products by plants; radium analysis in humans
1953 (GE 1954a)	• **Biological Sciences:** abundance and radioactivity of crustacea in the Columbia River; reactor effluent monitoring with Chinook salmon, effects of reactor effluent on cereal plants; absorption and translocation of plutonium-239 and cerium-144 by plants; physical and chemical properties of soil types; mutagenic effects of phosphorous-32; effects of tritium oxide on Chorella pyrenoidosa; hydrogen isotope incorporation in growing algae; rat studies with deuterium and tritium, studies on the absorption of plutonium in rats; absorption and distribution of ruthenium in fowl; radium abundance in cadavers from the Pacific Northwest; comparison of CaEDTA with zirconium citrate in promoting excretion of plutonium from the dog; toxicity of iodine-131 in sheep, beta irradiation of the skin of the sheep
1954 (GE 1955a)	• **Biological Sciences:** effects of reactor effluent on aquatic and plant life; plant and animal absorption and metabolism of several fission products, plutonium, and tritium; effects of iodine-131 and external radiation administered to sheep; toxicity of radioactive particles; new or improved techniques of possible application to radiobiology
1955 (GE 1956b)	• **Biological Sciences:** efficacy of isotopic dilution; effects of production facility effluents on biota; studies on radioactive particles; plant and microbiological studies of several radioisotopes; animal metabolism studies of several radioelements; biological effects of iodine-131 in sheep and pigs
1956 (GE 1957a)	• **Biological Sciences:** skin irradiation and decontamination; studies utilizing radioactive particles; plant and microbiological studies; effects of production facility effluents on biota
1957 (GE 1958d)	• **Biological Sciences:** uptake, distribution, and turnover of radioelements in plants, animals, and communities; biological effects of ionizing radiations on certain organs and organisms; effects of reactor effluent on plant and animal life
1958 (GE 1959a)	• **Biological Sciences:** strontium and calcium metabolism uptake in plants and animals; cesium accumulation by aquatic plants and animals; observations of biological effects of iodine-131 in sheep and swine; studies on the retention and elimination of plutonium in swine; studies to determine a safe daily limit for ingestion of phosphorus and zinc; tungsten metabolism in rats; polonium distribution in yeast; radioactive particles inhalation studies; radiation effects and protection experiments on rats; effects of production facility effluents on biota
1959 (GE 1960a)	• **Biological Sciences:** strontium-calcium and cesium-rubidium-potassium studies on rats, ewes and suckling lambs, plants, and soil; strontium toxicity studies on miniature swine and rainbow trout; physiology and therapy studies on miniature swine and rabbits; iodine studies on sheep, swine, and leaves; phosphorus studies in mice and fish; zinc studies in rats and ram; radioactive particles in mice; biological effects of radiation in the rat and yeast; laboratory techniques; environmental studies on contamination in wildlife, Chinook salmon, marine mollusks, and C. Columnaris

Year	Biological and Ecological Research Projects (As Indicated by Annual Reports)
1960 (GE 1961a)	• **Biological Sciences:** strontium and calcium metabolism and toxicity studies in Rainbow trout, rats, miniature swine, large animals, and meal moths; iodine metabolism and toxicity studies in sheep and swine, milk, and thyroids; zinc, cesium, cerium, neptunium, and plutonium metabolism and toxicity studies in pregnant ewes, sheep, rats, and rams; inhalation studies of plutonium and cerium-144 oxygen-2; physiology, therapy, and radiation effects on trout, yeast, bean plants, barley plants, mice, and rats; hematology studies on miniature swine, Pitman-Moore swine, and Palouse and Hormel swine; environmental studies on fish, marine organisms, salmon, geese, grass fields, and C. Columnaris
1961 (GE 1962a)	• **Biological Sciences:** strontium and calcium toxicity and metabolism studies in swine and trout; radioiodine toxicity and metabolism studies in sheep and swine; heavy elements toxicity and metabolism studies in milk; inhalation studies; modification of radioelement deposition and radiation response studies; animal and cellular physiology studies in water absorption and ingestion, regenerating liver, Ephestia larvae, proliferating cells, and yeast; plant physiology studies on barley plants and others; ecology studies on waterfowl, salmon, Columnaris, beetles, natural plant communities, desert soil, and Arctic plants and animals
1962 (GE 1963a)	• **Biological Sciences:** toxicity and metabolism of radioelements (transuranium and rare Earth elements; radioiodine; strontium; other elements; inhalation studies); modification of radioelement deposition and radiation response; animal and cellular physiology; plant physiology • **Ecology:** reactor effluent monitoring; Chinook salmon spawning near Hanford; swimming performance of Chinook salmon reared in reactor effluent; incidence and virulence of Columnaris; plankton-water chemistry cycles in the Columbia; soil moisture depletion in a sagebrush and a greasewood community; radiocesium in northern Alaskan Eskimos and their foods; gamma-emitting radionuclides in Alaskan fish and plants
1963 (GE 1964a)	• **Biological Sciences:** toxicity and metabolism of radioelements (radioiodine studies; inhalation studies; transuranium and rare Earth elements studies; strontium studies; other elements studies); modification of radioelement deposition and radiation response (removal of internally deposited plutonium; excretion of plutonium-239 in the intestine; effects of plutonium in swine; influence of internal emitters; graft-host response in xenogenic chimeras; etc.); animal and cellular physiology – various studies; plant physiology (deposition of iodine-131 on vegetation; accumulation of iodide by barley plants; cesium toxicity in plants; removal of plutonium-239, tungsten-185 and lead-210 from plants) • **Ecology:** second survey of radioactivity in northern Alaskan Natives and their foods; incidence and virulence of Columnaris; Chinook salmon spawning near Hanford; swimming performance of Chinook salmon reared in reactor effluent; toxicity of industrial chemicals to fish; plankton-water chemistry cycles in the Columbia; vegetational analysis in a sagebrush stand; potassium and sodium cycling by greasewood and hopsage
1964 (PNL 1965a)	• **Biological Sciences:** inhalation studies on beagles and rats; effects of strontium in miniature swine and molting crayfish; radioiodine effects on sheep and cattle, sheep milk, and skin exposure; effects of cesium on sheep, trout, and feed and rumen contents; effects of transuranium and other rare earth elements on sheep, fatty livers, and miniature swine; studies on zinc-65, cadmium-115m, copper, and x-rays; modification of radioelement deposition and radiation response studies on dogs, rats, and cows-to-man via milk; animal and cellular physiology studies on rats, flour beetles, chimeras, Escherichia Coli, Neurospora, lung mitochondria; plant physiology; ecological studies among Alaskan Natives, animals, and forage plants; nuclide fallout studies on plants and browsing animals in Washington; annual forage yield and fallout deposition in a cheatgrass community; Columbia River plankton studies; Chinook salmon spawning; and reactor effluent monitoring
1965 (PNL 1966a, 1966d)	• **Biological Sciences:** radiation effects – general; toxicity of radioelements; inhalation studies; combating detrimental effects of radiation; molecular and cellular level studies; environmental radiation studies – terrestrial and aquatic • **Geology and Hydrology:** stratigraphy of the uppermost part of the basalt sequence; variations in the gravity field at Hanford; prediction of vertical infiltration as influenced by errors; horizontal infiltration of liquids into porous media; extension of solution capabilities by finite differences method; etc • **Mineral Chemistry:** montmorillonite exchange equilibria with strontium-sodium-cesium; self-diffusion of sodium in vermiculite; exchange of alkali metal cations on a natural stilbite; alkali metal cation equilibria with chabazite; unit cell size and cesium loading; cation exchange properties; dispersion characteristics of strontium; cesium and strontium distribution beneath liquid waste disposal sites • **Particles and Gases:** application and performance of a spinning disc aerosol generator; subisokinetic sampling of particles in an air stream; errors in sampling with nozzles; particle deposition and re-entrainment in long vertical conduits; an iodine-131 generator for field release studies; release of noble gases from aqueous solution
1966 (PNL 1967a)	• **Biological Sciences:** inhalation studies on dogs, rats, leukemia patients, and lung tissue; space nuclear systems studies on dog lungs, swine, and rats; detrimental effects of radiation studies on swine; molecular and cellular studies; environmental radiation studies (terrestrial) on Alaskan Natives, Hanford geese and gulls, native rodents, plants, soil, and potato tubers; environmental radiation studies (aquatic) on trout, salmon, bottom organisms, other vertebrates, freshwater mussels, adult Caddis flies, Fairy shrimp, and Fisherola Nutalli

Year	Biological and Ecological Research Projects (As Indicated by Annual Reports)
1967 (PNL 1968a)	• **Biological Sciences:** radiation effects studies; strontium-90 studies in miniature swine; inhalation studies (dogs, rats); space nuclear systems studies (dogs, rats, leaves); radioelement toxicity studies (sheep, swine, rats); radioelement removal studies (rats, dogs); molecular and cellular level studies (Neurospora Crassa, human testes, intestinal cells, fish)
	• **Terrestrial Ecology Studies:** Eskimo food chain; rodents; Darkling beetles; desert plants; local soil; greasewood; cheatgrass
	• **Aquatic Ecology Studies:** Chinook salmon; Steelhead trout; bottom organisms; Sockeye salmon; freshwater mussels
1968 (PNL 1970a)	• **Biological Sciences:** radiation effects studies (rats, miniature swine, rabbits, mice); strontium-90 studies in miniature swine (various studies); inhalation studies (dogs, rats, etc.); radioelement toxicity studies (rats, sheep, swine, crustaceans); radioelement removal studies (rats, dogs, etc); molecular and cellular level studies (salmon, trout, etc)
1969 (PNL 1967d, 1970d, 1970e)	• **Biological Sciences:** gastrointestinal irradiation studies; irradiating skin; radiation and human spermatogenesis; radiation effects in mice; structural effects of temperature in fish; metabolism and effects of radionuclides in the developing fetus and the young; effects of radioiodine in sheep and swine; effects of radiostrontium in swine; radiation induced leukemogenesis in swine; inhalation studies (rats, dogs, uranium miners); space nuclear systems studies; removal of internal emitters; blood irradiators; malonaldehyde as a radiolysis product of biological materials
	• **Environmental Studies:** ecological micrometeorology and climatology of the ALE Reserve; geology and paleoecology of the ALE Reserve; hydrologic cycling on the ALE Reserve; characteristics of Hanford project soils
	• **Terrestrial Ecology Studies:** plant and animal ecology; mechanisms of transport and uptake of radionuclides in Alaska; mathematical simulation of radionuclide transfer and food chain processes
	• **Aquatic Ecology:** characteristics of Columbia River; freshwater ecology of Rattlesnake Springs; rates and mechanisms of biogeochemical processes of the Columbia; effects of modification on the Columbia River ecosystems
	• **Geology/Hydrology:** Yakima basalt formation; incidence of earthquakes at Hanford; geophysical seismic exploration; bouguer gravity anomalies in the Hanford Res.; acceleration factors for flow of fluids through soils; flow system surfaces; transport analysis
	• **Mineral Chemistry:** dispersion characteristics of strontium; geochemical processes; strontium and cesium equilibrium distribution coefficients; cation exchange properties
	• **Particles and Aerosols:** compact high speed spinning disc aerosol generator; particle deposition and re-entrainment in vertical conduits; etc.
1970 (PNL 1971a, 1971b)	• **Biological Sciences:** gastrointestinal irradiation studies; radiation effects; metabolism and effects of radionuclides in the developing fetus and the young; effects of radiostrontium in miniature swine; radiation-induced leukemogenesis; inhalation studies; low-level plutonium inhalation studies in beagles; inhalation hazards to uranium miners; space nuclear systems studies; removal of internal emitters; structural effects of temperature in fish; blood irradiators
	• **Terrestrial Ecology:** wildfire, animal ecology studies; plant ecology studies; ecological micrometeorology and climatology of the ALE Reserve; characteristics of Hanford soils; geology and paleoecology of ALE Reserve; Hydrologic cycling on the ALE Reserve; Alaska studies; analysis of natural systems
	• **Aquatic Ecology:** ecological characteristics of the Columbia River; freshwater ecology of Rattlesnake Springs; rates and mechanisms of biogeochemical processes of the Columbia River; effects of modification on the Columbia River ecosystems; effects of modification of the Columbia River ecosystems; effects of short range particle irradiation on embryogenesis of marine Teleost fish; fixation and long-term accumulation of tritium in an experimental aquatic environment
1971 (PNL 1972a, 1972b)	• **Biological Sciences:** gastrointestinal irradiation studies; effects of irradiating skin; radiation effects on chylomicron synthesis and capillary permeability in mice; miniature swine as model for intracavitary irradiation; cellular regulatory mechanisms; metabolism and effects of radionuclides in the developing fetus and the young among rats; effects on radiostrontium in miniature swine; radiation-induced luekemogenesis; inhalation studies among experimental animals; low-level plutonium inhalation studies in beagles; inhalation hazards to uranium miners (biological studies); space nuclear system studies; removal of internal emitters; fine structural effects of temperature in fish; development and evaluation of blood irradiators; biological effects of intracorporeal radioisotope heat source
	• **Aquatic Ecology:** effects of thermal discharge on aquatic biota; effects of tritium on aquatic environs; factors affecting biogeochemical cycling; synergistic effects of temperature, pollutants, and disease in aquatic organisms
	• **Terrestrial Animal Ecology:** perturbed environs; irradiation effects; population dynamics and reproductive habits; environmental quality; Alaska studies; analysis of natural systems

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	• **Terrestrial Plant Ecology:** vegetational dynamics and characterization; nutrient and hydrological factors; influence of environ factors on arid soil respiration rate; ecological micrometeorology and climatology of the ALE Reserve
1972 (PNL 1973a, 1973b)	• **Biological Sciences:** toxicology of ingested, injected, and topically applied radionuclides (swine, rats); toxicology of inhaled plutonium and transplutonium elements (rats, dogs, etc.); inhalation hazards to uranium miners (beagles, hamster, rats, mice, mine atmosphere); evaluation of radionuclides in man; removal of radionuclides (rats, etc.); nuclear-powered prostheses and other human applications; mechanisms of radiation effects; • **Plutonium Studies:** interactions of plutonium aerosols with plant foliage; Nevada test site; behavior of waste radionuclides in soil-plant systems; methods for measuring plutonium complexation in soil and uptake by plants • **Marine Sciences:** thermal resistance; effects of short-range particle irradiation; geochemical ocean sections study (GEOSECS); physical and radiological chemistry of ocean solutions • **Analysis of Natural Systems:** sampling for radionuclides and other trace substances; bias in capture-recapture studies; sampling sagebrush on ALE; Antarctic seal study • **Characteristics of Hanford Soil and Aquatic Sediments:** influence of environmental factors on arid soil respiration rate; temperature and moisture; livestock grazing; mercury levels in particulate matter suspended in waters of Lower Columbia watershed • **Freshwater Ecology:** effects of thermal discharge on aquatic biota; effects of tritium on aquatic environs; factors affecting biogeochemical cycling; combined effects of temperature, pollutants, and disease in aquatic organisms • **Terrestrial Ecology:** terrestrial plant ecology studies; grasslands biome; terrestrial animal ecology; Alaska studies
1973 (PNL 1974a, 1974b)	• **Biological Sciences:** toxicology of ingested, injected, and topically applied radionuclides in rats, miniature swine, and mice; toxicology of inhaled plutonium and transplutonium elements in dogs, rats, and other rodents; inhalation hazards to uranium miners with rats, mice, and dogs; evaluation of radionuclides in man; removal of radionuclides in rats, miniature swine, and blood; mechanisms of radiation effects in N. Crassa, miniature swine, and mammalian cells • **Analysis of Natural Systems:** quantitative ecological aspects of nuclear power development; sampling for contaminants; modeling ecological systems; statistical and mathematical aspects of ecology • **Environmental Chemistry:** the potential for plutonium complexation in soil and uptake by plants; characteristics of Hanford soils and aquatic sediments; fate and effects of oil on marine coastal ecosystems; Hanford intercontractor support; radioecology of iodine-129; suspended particle interaction • **Freshwater Ecology:** effects of thermal discharge on aquatic biota and fish behavior and sensory physiology; combined effects on temperature, pollutants, disease; effects of tritium on aquatic environs; factors affecting biogeochemical cycling • **Marine Sciences:** bioenvironmental effects of effluents discharge from nuclear power plants to coastal waters; fate and effects of oil on marine coastal ecosystems; physical and radiological chemistry of ocean solutions; geochemical ocean study section (GEOSECS) • **Radiological Sciences:** radiological health research; iron-55 in human populations; radioanalytical procedures development; fate and effects of radionuclides in Alaska • **Terrestrial Ecology:** energy and water relations; mineral nutrients; manipulated ecosystems; consumer studies; primary producer studies; radiation studies; modeling
1974 (PNL 1975a, 1975b)	• **Biological Sciences:** low-level plutonium and transplutonium oxide inhalation studies in beagles; toxicology of inhaled plutonium and transplutonium elements in rodents; toxicology of inhaled beryllium compounds; development of aerosol exposure and analytical techniques; mechanisms of inhaled plutonium toxicity; toxicology of radionuclides in the fetal and juvenile mammal (rats); factors modifying radionuclide metabolism and effect in mice; toxicology of chronically fed strontium-90 in miniature swine; gut related studies of radionuclide toxicity (rats); acute toxicity of reactor catastrophe effluent; inhalation hazards to uranium miners (dogs, hamsters, rats, mice); evaluation of radionuclides in man (tissue samples, Richland school children); treatment for radionuclide incorporation (rats, dogs); chemical radiation protection; mechanisms of radiation effects (N. Crassa, miniature swine, leukemia virus) • **Analysis of Natural Systems:** sampling for contaminants; modeling ecological systems; statistical and mathematical aspects of ecology; quantitative ecology of impact evaluation

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	• **Environmental Chemistry:** potential for plutonium complexation in soil and uptake by plants; characteristics of Hanford soils and aquatic sediments; suspended particle interactions; Hanford intercontractor support
	• **Environmental Impact Assessments**
	• **Freshwater Sciences:** thermal effects on aquatic biota; combined effects of temperature and pollutants on fish; cold shock; Gable Mountain pond studies; salmon spawning studies; effects of modifications on aquatic ecosystems; ecological distribution and fate of plutonium and americium in processing waste ponds; effects of tritium on aquatic systems
	• **Marine Sciences:** non-nuclear effluents; thermal effects of effluent discharges; biological availability and effects of effluents; effects of low-level chronic irradiation; physical and radiological chemistry of ocean solutions; geochemical ocean sections study (GEOSECS); in situ pollutant studies; biogeochemistry of plutonium and americium in marine systems
	• **Radioanalytical Procedures Development**
	• **Terrestrial Ecology**
1975 (PNL 1976a, 1976b)	• **Biological Sciences:** development of aerosol exposure and analytical techniques; biological behavior of plutonium released with sodium; low-level plutonium and transplutonium oxide inhalation studies in beagles; low-level plutonium nitrate inhalation studies in beagles; toxicology of inhaled plutonium and transplutonium elements in rodents; disposition and biological effects of inhaled plutonium in miniature swine; inhalation hazards to uranium miners; inhalation hazards to coal miners (coal and diesel engine exhaust); toxicology of tritium and the noble gases; delayed effects of exposure to acid aerosols; toxicology of radionuclides in the fetal and juvenile mammals; factors modifying radionuclide metabolism and effects; gut-related studies of radionuclide toxicity; acute toxicity of reactor-catastrophe effluent; toxicology of chronically fed strontium-90 in miniature swine; biochemical indices of pollutant carcinogenicity; effects of pollutant metals in nutritionally deficient populations; effects of inhaled oil shale and spent shale particles in animals; evaluation of radionuclides in man; chemical radiation protection; treatment of radionuclide incorporation; treatment of toxic metal exposure associated with non-nuclear technologies; blood irradiation for medical applications; mechanisms of radiation effects; interaction of fossil-fuel derived toxic metals with biological membranes; biological effects of intracorporeal radioisotope heat sources; artificial heart program; alveolar clearance of inhaled metal oxides; effects of sulfur pollutants on lung physiology and biochemistry
	• **Analysis of Natural Systems:** sampling and modeling; population studies; statistical and mathematical aspects of ecology; quantitative ecology of impact evaluation; quantitative aspects of environmental plutonium studies
	• **Environmental Chemistry:** the potential for plutonium complexation in soil and uptake by plants; influence of soils and aquatic sediments on the chemical behavior, transport, and bioavailability of pollutants resulting from energy production; suspended particle interactions
	• **Freshwater Sciences:** effects of thermal discharges on aquatic biota; combined effects of waste heat and environmental factors acting in concert; effects of hydroelectric generation on riverine ecology; effects of water quality alterations on fish behavior; effects of behavior of fossil fuel elements in freshwater ecosystems Pacific Northwest energy related regional studies program; ecological distribution and fate of plutonium and americium in a processing pond; sublethal effects of tritium on aquatic systems; salmon spawning studies
	• **Marine Sciences:** effects of thermal discharges to coastal waters; non-nuclear effluents; bioavailability and impact of effluents on coastal ecosystems; effects of low-level chronic irradiation on embryonic development of marine fish and invertebrates; biogeochemistry of plutonium and americium in the marine environ; physical and radiological chemistry on ocean solutions; geochemical ocean sections study (GEOSECS)
	• **Radioanalytical Procedure Development**
	• **Terrestrial Ecology:** Hanford Reservation support services; weathering and aging of transurانics and radioecology of iodine-129; ecological micrometeorology and climatology of the ALE Reserve; terrestrial ecology studies; grassland biome; terrestrial animal ecology studies
	• **Shale Oil:** terrestrial effects of oil shale development; development of chemical reactions, stability and transport model of oil shale process wastes in soil
	• **Oil and Gas:** fate and effects of petroleum hydrocarbons in marine coastal ecosystems; long-term effects of hydrocarbons on selected ecosystems and associated organisms
	• **Nuclear Wastes (Fission):** suspended particle interactions and uptake in terrestrial plants; transuranic complexation in soil and uptake by plants; quantitative aspects of plutonium field studies; ecological distribution and fate of plutonium and

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	americium in a processing waste pond on the Hanford Reservation; use of analog elements to predict the equilibrium behavior of transuranic elements in the environ; weathering and aging of transuranics; biogeochemistry of plutonium and americium in the marine environ; radioecology of waste management areas (ROWMA); radioecology of uranium; radioecology of iodine-129 and technitium-99; influence of soils and aquatic sediments on the chemical behavior, transport, and bioavailability of pollutants • **Nuclear Fusion:** reviews for division of magnetic fusion energy; sublethal effects of tritium on aquatic systems; effects of low-level chronic irradiation on embryonic development of marine fish and invertebrates • **Solar Hydroelectric Generation:** effects of hydroelectric generation on riverine ecology • **Multitechnology Report:** analysis of natural systems; quantitative ecology of impact evaluation; geochemical ocean sections study (GEOSECS); chemistry of ocean solutions; in situ pollutant study of the New York bight; effects of water quality alterations on fish behavior; effects of thermal discharges on aquatic biota; combined effects of waste heat and environmental factors acting in concert; power plant heat and chemical effluent effects on selected marine and estuarine communities; immediate effects of anti-fouling biocides from coastal and offshore power plants; effects of thermal discharges to coastal waters; biological availability of energy related effluent material in the coastal ecosystem • **Hanford Support Services:** ARHCO studies • **Land Use and Coal Technology:** Hanford National Environmental Research Park (NERP) and ALE administration; terrestrial ecology; restoration of surface-mined lands; fossil fuel effluents in freshwater ecosystems • **Nuclear Wastes (Fission):** suspended particle interaction and uptake in terrestrial plants; transuranic complexation in soil and uptake by plants; quantitative aspects of plutonium field studies; ecological distribution and fate of plutonium and americium in a processing waste pond; use of analog elements to predict the equilibrium and behavior of transuranic elements in the environment; weathering and aging of transuranics; radioecology of uranium and waste management areas; transport and bioavailability of pollutants • **Nuclear Fusion:** biomagnetic effects; sublethal effects of tritium on aquatic systems; effects of low-level chronic irradiation on embryonic development of marine fish and invertebrates; effects of beryllium and lithium on aquatic systems; terstogenic effects of low-level magnetic fields • **Oil and Gas:** fate and effects of petroleum hydrocarbons in marine coastal ecosystems; effects of refinery wastes and oil from transfer facilities; long-term effects of hydrocarbons on selected ecosystems and associated organisms • **Hydroelectric Generation:** effects of hydroelectric generation on riverine ecology
1978 (PNL 1979a, 1979b)	• **Coal:** inhalation hazards to miners; lung toxicity; effects of pollutant metals; alveolar clearance of inhaled metal oxides; factors influencing cross-placental transfer and tetrogenicity of metallic pollutants; solvent refined coal biostudies • **Conservation:** mutagenic effects of electric fields • **Fission:** aerosol and analytical technology; inhaled plutonium oxide/nitrate in dogs; inhaled transuranics in rodents; toxicology of plutonium-sodium/sodium; inhalation hazards to uranium miners; toxicology of krypton-85; toxicology of thorium cycle nuclides; fetal and juvenile radiotoxicity; modifying radionuclide effects; gut-related studies of radionuclide toxicity; removal of deposited radionuclides; viral and radiation carcinogenesis; blood irradiators; cigarette smoke and plutonium • **Fusion:** biomagnetic effects • **Oil Shale:** late effects of oil shale pollution; mutagenicity of oil shale; development • **Multitechnology:** toxicology of inhaled acid aerosols; mobilization of deposited metals; metal-membrane interactions toxic effects of geothermal effluents • **National Environmental Research Park & Land Use:** various • **Synfuels:** various • **Oil and Gas:** fate and effects of petroleum hydrocarbons in marine ecosystems; long-term effects of hydrocarbons on ecosystems and organisms

Year	Biological and Ecological Research Projects (As Indicated by Annual Reports)
	• **Nuclear Wastes:** transuranic behavior in soils and plants; quantitative aspects of plutonium field studies; analog elements for transuranic chemistry; transuranic weathering in plants; radioecology of nuclear fuel cycles; environ behavior and effects of technetium and iodine
	• **Nuclear Fusion**
	• **Solar/Hydroelectric Generation**
	• **Satellite Power Systems**
	• **Multitechnology and Supporting Research**
	• **Alaskan Environmental Research**
1979 (PNL 1980a, 1980b)	• **Coal:** inhalation hazards to coal miners; effects of pollutant metals; alveolar clearance of inhaled metal oxides; factors influencing the cross-placental transfer and teratogenicity of metallic pollutants; solvent refined coal biostudies; perinatal effects of pollutants; mutagenicity of synfuels
	• **Conservation:** mutagenic effects of electric fields; electric field dosimetry; in vivo mutagenesis (electric fields); in vitro effects on electric fields
	• **Fission:** aerosol and analytical technology; inhaled plutonium oxide and plutonium nitrate in dogs; inhaled transuranics in rodents; cigarette smoke and plutonium; toxicology of plutonium-sodium; toxicology of sodium and lithium; inhalation hazards to uranium miners; toxicology of krypton-85; toxicology of thorium cycle nuclides; fetal and juvenile radiotoxicity; modifying radionuclide effects; gut-related studies of radionuclide toxicity; removal of deposited radionuclides; viral and radiation carcinogenesis; development of blood irradiators; transuranic behavior in soils and plants; quantitative aspects of transuranic field studies; analog elements for transuranic field studies; transuranic weathering in plants; radioecology of nuclear fuel cycles; environmental behavior and effects of technetium-99 and iodine-129
	• **Fusion:** biological effects of magnetic fields; sublethal effects of tritium on aquatic systems; ecological effects of lithium and beryllium on important aquatic organisms and communities
1980 (PNL 1981a, 1981b)	• **Coal Studies:** inhalation hazards to coal miners; pollutant metals and malnutrition; alveolar clearance of inhaled metal oxides; factors influencing the cross placental transfer and teratogenicity of metallic pollutants
	• **Conservation:** mutagenic effects of electric fields; AC E-field dosimetry; in vivo mutagenesis; in vitro effects of electric fields
	• **Fission:** aerosol technology development; inhaled plutonium oxide/nitrate in dogs; inhaled transuranics in rodents; cigarette smoke and plutonium; toxicology of plutonium-sodium/sodium-lithium; inhalation hazards to uranium miners; toxicology of krypton-85; toxicity of thorium cycle nuclides; fetal and juvenile radiotoxicity; modifying radionuclide effects; gut-related studies of radionuclide toxicity; viral and radiation carcinogenesis; blood irradiators
	• **Fusion:** biological effects of magnetic fields
	• **Oil Shale:** health effects of synthetic fuels, terrestrial effects of development
	• **Multitechnology:** toxicology of inhaled acid aerosols; metal-membrane interactions; toxic effects of geothermal effluents
	• **National Environmental Research Park & Land Use:** terrestrial ecology; dynamics of wild populations; restoration of surface-mined lands; long-term ecological monitoring; application of long-term chemical biobarriers for U-tailings; re-vegetation
	• **Alaskan Resource Research:** ecological investigation of Alaskan resource development
	• **Synfuels:** ecological effects of coal conversion; toxicology
	• **Nuclear Waste (Fission):** transuranic behavior; analogs for transuranics; long-term plant availability of actinides; radioecology of nuclear fuel cycles; environmental behavior and effects of technetium and Iodine
	• **Marine Research Programs:** effects of energy systems effluents; bioavailability of effluent materials in coastal ecosystems; marine chemistry

Year	Biological and Ecological Research Projects (As Indicated by Annual Reports)
	• **Nuclear Fusion:** sublethal effects of tritium on aquatic systems; ecological effects of lithium and beryllium on aquatic communities; teratogenic effects of low-level magnetic fields
	• **Pumped Storage & Hydroelectric Development**
	• **Electric Field & Microwave Research**
1981 (PNL 1982a, 982b)	• **Coal:** mutagenicity of SRC materials; solvent refined coal biostudies; health effects of synthetic fuels; perinatal effects of SRC; teratology of SRC-II materials; inhalation hazards to miners; factors influencing the cross-placental transfer and teratogenicity of metallic pollutants
	• **Conservation:** mutagenic effects of electric fields; electric field dosimetry; in vivo mutagenesis of electric fields; in vitro effects of electric fields
	• **Fission:** aerosol technology development; inhaled plutonium oxide/nitrate and americium dioxide in dogs; inhaled transuranics in rodents; low-level plutonium-239 oxygen-2 lifespan studies; toxicology of plutonium-sodium; cigarette smoke and plutonium; toxicity of sodium and lithium; inhalation hazards to uranium miners; toxicology of krypton-85; toxicity of thorium cycle nuclides; fetal and juvenile radiotoxicity; gut-related radionuclide studies; statistical health effects studies; radioisotope customer list
	• **Fusion:** biological effects of magnetic fieldsMultitechnology: metal-membrane interactions; alveolar clearance of inhaled metal oxides
	• **Multitechnology:** metal-membrane interactions; alveolar clearance of inhaled metal oxides.
	• **National Environmental Research Park & Land Use:** terrestrial ecology; dynamics of wild populations; quantifying energy-related effects on mobile species; restoration of surface mined lands; long-term ecological monitoring; application of long-term chemical biobarriers for U-tailings; re-vegetation
	• **Alaskan Resource Research:** ecological investigation of Alaskan resource development
	• **Shale Oil:** terrestrial effects of development
	• **Synfuels:** ecological effects of coal conversion; coal liquefaction health and environmental effects
	• **Nuclear Waste (Fission):** transuranic element behavior; transuranic chemical species in ground water; quantitative aspects of transuranic and other radionuclide field studies; analog elements for transuranic chemistries; long-term plant availability of actinides; radioecology of nuclear fuel cycles; environmental behavior of technetium-99 and iodine-129
	• **Marine Research:** trace metals metabolism in marine animals; bioavailability of energy-effluent materials in coastal ecosystems; marine chemistry of energy related pollutants
	• **Nuclear Fusion:** sublethal effects of tritium on aquatic systems ecological effects of lithium and beryllium on aquatic communities; teratogenic effects of low-level magnetic fields
	• **Pumped Storage & Hydroelectric Development:** effects of hydroelectric generation on riverine ecology
	• **Pathways Modeling, Assessment, and Hanford Project Support**
	• **Electric Field Research**
1982 (PNL 1983a, 1983b)	• **Coal Studies:** mutagenicity of SRC materials; solvent refined coal biostudies; health effects of synthetic fuels; perinatal effects of SRC; teratology of SRC-II materials; effect of pollutant metals
	• **Conservation:** teratology of guinea pigs exposed to electric fields; mutagenic effects of electric fields; electric field dosimetry; in vitro effects of electric fields
	• **Fission:** aerosol technology development; inhaled plutonium oxide/nitrate in dogs; inhaled transuranics in rodents; low-level plutonium-239 oxygen-2 lifespan studies; cigarette smoke and plutonium; toxicity of sodium and lithium; inhalation hazards to uranium miners; toxicology of kryton-85; toxicity of thorium cycle nuclides; modifying radionuclide effects; fetal and juvenile radiotoxicity; gut-related radionuclide studies; blood irradiators; health effects studies; radioisotope customer list
	• **Fusion:** biological effects of magnetic fields

Year	Biological and Ecological Research Projects (As Indicated by Annual Reports)
	• **Multitechnology:** metal-membrane interactions; alveolar clearance of inhaled metal oxides
	• **Terrestrial and Riverine Ecology:** terrestrial ecology; response of Columbia River fish to man-induced flow alterations; determination of long-term biological responses; ecological investigations in Alaska
	• **Marine Research:** entrance, behavior, and fate of trace metals in coastal waters; transport and bioavailability of trace metals in coastal ecosystems; biological effects of trace metals on marine animals
	• **Ecological Effects on Coal Conversion:** transport and fate; effects on aquatic and terrestrial systems; food chain transfer
	• **Solid Wastes (Mobilization, Fate, and Effects)**
	• **Radionuclide Fate and Effects:** environmental transport processes; radionuclide transport parameters; ecological interactions influencing remedial actions at waste sites; transuranic chemical species in groundwater; analogs for transuranic chemistries
	• **Statistical and Theoretical Research:** examining the fate of contaminants from energy developments; censuring wild and stray populations of large animals; designing studies to detect effects on mobile species
	• **Statistical and Quantitative Research:** developing methods to evaluate environmental behavior of radionuclides and population dynamics of large animals
1984 (PNL 1985a, 1985b)	• **Human Health Effects from Energy Generation:** statistical health effects study
	• **Carcinogenesis:** biostudies of complex mixtures; inhaled plutonium oxide/nitrate in dogs; low-level 239PuO2 lifespan studies; cigarette smoke and plutonium; toxicology of thorium cycle nuclides; inhalation hazards to uranium miners; fetal and juvenile radiotoxicity
	• **Mutagenesis:** mutagenicity of complex mixtures
	• **Systems Damage:** gut-related studies of radionuclides; teratology of complex mixtures; perinatal effects of complex mixtures; tissue dose in fossil fuel exposure; aerosol technology development; biological effects of magnetic fields
	• **General Life Sciences:** metal-membrane interactions
	• **Health and Environmental Risk Analysis:** complex mixtures-relative potency matrix
	• **Medical Applications of Nuclear Technology:** blood irradiators; radioisotope customer list
	• **Western Arid and Semi-Arid Ecosystems:** NERP; dynamics of arid land ecosystems
	• **Marine Sciences:** toxicity of sea-surface contaminants; metabolism of trace metals in marine animals; uptake and depuration of silver in mussels; partitioning coefficients (Kp) for metals in sediments and water column
	• **Mobilization, Fate, and Effects of Energy-Derived Chemicals:** hydrochemical phenomena controlling solute behavior; contaminant transfer through aquatic organisms
	• **Radionuclide Transport Research:** characterization of plant-produced ligands; metabolic behavior of technetium in plants; radionuclides transported by insects and fish
	• **Statistical and Quantitative Research on Wild Populations:** population studies of large animals; quantifying energy-related effects on mobile species
1985 (PNL 1986a, 1986b)	• **Human Health Effects:** statistical health effects study
	• **Health Effects of Radiation:** inhaled plutonium oxide/nitrate in dogs; oncogenes in radiation carcinogenesis; cigarette smoke and plutonium; low-level plutonium-239 oxygen-2 lifespan studies; inhalation hazards to uranium miners; toxicology of thorium cycle nuclides; aerosol technology development; fetal and juvenile radiotoxicity; gut-related studies of radionuclides
	• **Health Effects of Chemical Mixtures:** mutagenicity of complex mixtures; biostudies of complex mixtures; teratology of complex mixtures; perinatal effects of complex mixtures; health effects of complex mixtures; tissue dose in exposure to complex mixtures
	• **Medical Applications of Nuclear Technology:** blood irradiators; radioisotope customer list

Year	Biological and Ecological Research Projects (As Indicated by Annual Reports)
	• **Arid Land Sciences:** dynamics of arid land ecosystems; ecological studies at the NERP; biotic transport research
	• **Marine Sciences:** marine chemistry of energy-related contaminants; environmental stress and disease in marine animals; trace metal metabolism in marine animals
	• **Biogeochemical Phenomena in Indirect Exposure Pathways:** soil and plant processes controlling cation behavior in terrestrial systems; environmental behavior of inorganic anions; bioaccumulation and biochemical behavior of xenobiotic organic compounds in terrestrial systems; aquatic food chain transfer
	• **Subsurface Transport:** subsurface behavior of organic compounds and mixtures; hydrogeochemical phenomena controlling solute behavior
	• **Theoretical (Quantitative) Ecology:** dynamics of wild populations; quantifying energy-related impacts on mobile species; designs for environmental field studies
1986 (PNL 1987a, 1987b)	• **Human Health Effects:** statistical health effects study
	• **Health Effects of Radiation:** inhaled plutonium oxide/nitrate in dogs; oncogenes in radiation carcinogenesis; low-level plutonium-239 oxygen-2 lifespan studies; inhalation hazards to uranium miners; toxicology of thorium cycle nutrients; aerosol technology development; fetal and juvenile radiotoxicity; gut-related studies of radionuclides
	• **Health Effects of Chemical Mixtures:** mutagenicity of complex mixtures; complex mixtures biostudies; teratology of complex mixtures; perinatal effects of complex mixtures; tissue dose in complex mixture exposures
	• **Medical Applications of Nuclear Technology:** blood irradiators for medical applications development; radioisotope customer list
	• **Environmental Sciences:** detecting and managing change in terrestrial ecosystems; remote sensing; biotic transport processes in arid ecosystems; installation of precision-weighing lysimeters for evapotranspiration measurements at Hanford's ALE Reserve; biogeochemical phenomena; subsurface transport; marine sciences; theoretical ecology; exploratory research; university interactions; technology transfer
1987 (PNL 1988a, 1988b)	• **Human Health Effects Research:** statistical health effects study; iron stores and risk of cancer; interlaboratory toxicology data base; benefit-cost analysis of OHER research
	• **Health Effects Research in Biological Systems:** inhaled plutonium oxide/nitrate in dogs; inhalation hazards to uranium miners; mechanisms of radon injury; aerosol technology development; oncogenes in radiation carcinogenesis; molecular events during tumor initiation; fetal and juvenile radiotoxicity; molecular markers during development; molecular control of lung development; mutational studies in DNA targets
	• **Medical Applications of Nuclear Technology:** radioisotope customer list and shipment summary
	• **Environmental Sciences:** detecting and managing change in terrestrial ecosystems; biogeochemical phenomena; subsurface transport; marine sciences; theoretical ecology; exploratory research; university interactions; technology transfer; international relations
1988 (PNL 1989a, 1989b)	• **Human Health Effects Research:** statistical health effects study; iron stores and risk of cancer; interlaboratory toxicology knowledge base
	• **Health Effects Research in Biological Systems:** inhaled plutonium oxide/nitrate in dogs; low-level plutonium-239 oxygen-2 studies; inhalation hazards to uranium miners; mechanisms of radon injury; microdosimetry of radon daughters; growth factors in radiation carcinogenesis; oncogenes in radiation carcinogenesis; molecular events during tumor initiation; aerosol technology development; fetal and juvenile radiotoxicity; molecular markers during development; molecular control of lung development; mutation of DNA targets; synthesis of human genome information; genome graphics interface
	• **Medical Applications of Nuclear Technology:** radioisotope customer list
	• **Detecting and Managing Change in Terrestrial Ecosystems:** arid lands water balance; the effect of water and nitrogen perturbations on gas exchange in arid lands ecosystems; spatial variability in ecological factors influencing surface water distribution in the shrub-steppe; measuring landscape-level processes; floristics and climate in the deserts of Western United States

Year	Biological and Ecological Research Projects (As Indicated by Annual Reports)
	• **Biochemical Phenomena:** soil and plant processes controlling cation behavior in terrestrial systems; environmental behavior of inorganic anions
	• **Subsurface Science:** subsurface chemistry of organic chemical mixtures; subsurface behavior of organic fluids; radon transport modeling in soils; a finite element model of radon advection and diffusion in unsaturated cracked soils; subsurface microbial phenomena
	• **Marine Sciences:** environmental stress and disease in marine invertebrates
	• **Theoretical Ecology:** designs for environmental field studies; dynamics of wild populations; quantifying energy-related effects on mobile species
	• **Exploratory Research:** biogenic cycling of volatile nitrogen-containing species; remote thermal data for determining evapotranspiration in arid landscapes; comparison of techniques to elucidate adsorption phenomena in aqueous solutions; optimal measurement scales and experimental design for detecting and predicting global ecosystem change; variability and speciation of atmospheric mercury; environmental detection and fate of genetically engineered microorganisms; modeling salmon spawning habitat through remote sensing and geographic information system techniques
1989 (PNL 1990a, 1990b)	• **Human Health Research:** statistical health effects studies; iron stores and risks of cancer
	• **Biological Research:** inhaled plutonium oxide and plutonium nitrate in dogs; national radiobiology archives; low-level plutonium-239 oxygen-2 life-span studies; inhalation hazards to uranium miners; mechanisms of radon injury; microdosimetry of radon daughters; growth factors in radiation carcinogenesis; oncogenes in radiation-induced carcinogenesis; molecular events during tumor initiation; mutation of DNA targets; fetal and juvenile radiotoxicity; aerosol technology development
	• **General Life Sciences Research:** synthesis of human genome information; GnomeView, a graphical interface to the human genome
	• **Medical Applications:** radioisotope customer list
	• **Detecting and Managing Change in Terrestrial Ecosystems:** understanding terrestrial ecosystems; landscape ecological studies; arid lands water balance; a microcosm-level gas exchange study
	• **Subsurface Science:** subsurface microbial phenomena; groundwater dating at the SRS; subsurface chemistry of organic compounds and mixtures; chemistry/microbiology controlling chelated radionuclide transport; intermediate-scale subsurface transport of co-contaminants; subsurface flow physics of immiscible organic liquids; subsurface science program liaison; estimating steady date diffusive and advective fluxes from different soil types
	• **Marine Sciences:** cause and progression of leukemia in a marine invertebrate
	• **Theoretical Ecology:** dynamics of wild populations; designs for environmental field studies
	• **Exploratory Research:** biogenic cycling of volatile nitrogen-containing species; optimal measurement scales and experimental design for detecting and predicting global ecosystems change; a knowledge-based system for evaluating human disturbance and global climate change in arid regions; remote sensing of plant stress; fluxes of biogenic gases from the ocean surface; development of a passive diffusion sensor for the measurement of ambient mercury vapor concentrations
1990 PNL 1991a, 1991b)	• **Human Health Research:** statistical health effects studies; Tatum Dome cancer incidence study; iron stores and risk of cancer
	• **Biological Research:** inhaled plutonium oxide and plutonium nitrate in dogs; national radiobiology archives; low-level plutonium-239 oxygen-2 life-span studies; inhalation hazards to miners; mechanisms of radon injury; dosimetry of radon progeny; aerosol technology development; growth factors in radiation carcinogenesis; oncogenes in radiation-induced carcinogenesis; mutation of DNA targets; molecular events during tumor initiation; genotoxicity of inhaled energy effluents; fetal and juvenile radiotoxicity
	• **General Life Sciences Research:** GnomeView II, a graphical interface to the human genome; synthesis of human genome information
	• **Subsurface Science:** subsurface chemistry of organic chemical and organic-radionuclide mixtures; subsurface microbial phenomena; hydrogeologic and geochemical controls on microorganisms; pore water chemistry; chemistry/microbiology controlling chelated radionuclide transport; subsurface organic fluid flow research; intermediate-scale subsurface transport of co-contaminants

Year	Biological and Ecological Research Projects (As Indicated by Annual Reports)
	• **Terrestrial Science:** vegetation as a controlling influence in shrub-steppe water balance; landscape ecological studies; gas exchange dynamics and the effects of nitrogen and water; effects of soil water deficit and plant age; dynamics of soil inorganic nitrogen; the effects of fire on nitrous oxide flux; dominated old-fields; artificial intelligence in environmental research; environmental research parks; designs for environmental field studies
	• **Exploratory Research:** engineered microbes; contaminant transport modeling; Hollaender fellowship in contaminant transport; geostatistics; monitoring network design for risk-based groundwater remediation; remote sensing of plant stress; optimal measurement scales and experimental design for detecting and predicting global ecosystems change

Physical Science Research Projects at the Hanford Site, 1951–1990

Year	Physical Science Research Projects (As Indicated by Annual Reports and with Asterisk by Quarterly Reports)
1951 (Mickelson 1951)	• **Radiological Records and Standards:** general; design standards; radiation monitoring activities; instrument calibrations
	• **Biophysics:** general; control laboratory and counting room; regional survey; synoptic meteorology; control services; experimental meteorology; geology; industrial hygiene; methods; radiochemical standards; soil science
1952 (GE 1952b)	• **Biophysics:** REDOX stack effluent gas and process water studies; determination of oil content in oil fog dispersion; radioactive isotopic build-up in 100-C reactor effluent; recirculated water analysis for 100-H; environmental contaminants originating from Hanford
	• **Synoptic/Experimental Meteorology:** weather forecasts; climatological statistics; oil-fog studies; air contaminant trajectory studies
	• **Geology/Hydrology:** drilling exploration; ground water contamination studies
	• **Industrial Hygiene/Medical:** particle exposure studies from 200 Areas, REDOX stack, 314 Building; non-radioactive health hazard studies (toxic metals, gases, or vapors)
	• **Instrument Development:** single channel gamma spectrometer using a sodium iodine acintillator; portable alpha survey instruments with scintillation detectors; C.P. meter; equipment for measuring the temperature below the river bottom; equipment for monitoring test wells; recording anemometer using an uninterrupted light beam; metal evaporator; etc.
	• **Soil Science:** absorption of cesium; studies of tank waste solutions penetrating the groundwater; accumulated sludge in the 105-H storage basin; polargraphic procedure for determining the total cation exchange capacities of soil
	• **Physics**
1953 (GE 1954c)	• **Radiological Engineering**
	• **Radiological Records and Standards**
	• **Biology Studies:** general; aquatic; metabolism and toxicology; biology controls
	• **Biophysics Section:** general; control laboratory and counting room; regional survey; synoptic meteorology; control services; experimental meteorology; earth sciences; industrial hygiene; instrument development; methods; physics; radiochemical standards
1954 (GE 1954d)	• **Radiological Engineering:** disposal of liquid wastes; disposal of process wastes to Columbia River; improvement of radiation protection design criteria; mechanical development
	• **Biology Program:** deduction of permissible human exposure by biological experimentation; effects of process effluents on aquatic organisms; effects of process effluent on plants and animals
	• **Biophysics Program:** monitoring methods; environmental studies and adequacy of waste disposal systems; instrumentation for radiation detection and measurement

Year	Physical Science Research Projects (As Indicated by Annual Reports and with Asterisk by Quarterly Reports)
1955 (Mickelson 1955)	• **Radiological Engineering:** disposal of liquid wastes from separations processes; disposal of process wastes to Columbia River – effluent dispersion patterns, ruptured fuel element waste disposal, downstream domestic usage of river water, reactor purge waste disposal, disposal of reactor experimental control solution, metal preparation area waste disposal; Columbia River studies • **Radiation Protection Design:** radiological disaster studies; radioactive particle hazard studies; hazards of possible process materials • **Mechanical Development** • **Biology Program:** deduction of permissible human exposure by biological experimentation – tritium absorption and metabolism, fission product absorption and metabolism, plutonium and absorption, respiratory metabolism and toxicity of radioactive particles, skin irradiation; effects of process effluents on aquatic organisms; effects of process effluent on plant and animal life – effect of reactor effluent on plants, absorption and translocation of radioelements on plants, toxicity of iodine-131 in animals • **Biophysics Program:** analytical methods; monitoring methods; counting methods; bioassay methods; special studies; geological studies; soil chemistry; soil physics; process waste disposal; diffusion and transport study; particle pick-up study; trajectory study (200 mile scale); atmospheric contamination problems; aerosol sampling; respirator testing; toxic materials • **Dosimetry:** gamma ray dosimetry; beta ray dosimetry; neutron dosimetry • **Instrumentation:** survey instrumentation; biological instrumentation; laboratory instrumentation; special purpose instrumentation
1956* (GE 1956c, 1956d, 1957b, Parker 1956)	• **Biology Program:** aquatic biology studies; experimental animal farm studies; metabolism studies; pharmacology and experimental therapeutics; plant nutrition and microbiology; minor problems research; biological analyses • **Biophysics:** chemical and monitoring methods; geological studies; meteorology studies; industrial hygiene studies • **Dosimetry Program:** gamma ray; beta ray; and neutron dosimetry; body monitor • **Instrumentation Program:** survey; biological; laboratory; and special purpose instrumentation • **Chemistry and Separations:** analytical chemistry; chemical effluents technology
1957* (GE 1957c, 1957d)	• **Biology Program:** aquatic biology; experimental animal farm; metabolism studies; pharmacology studies; plant nutrition and microbiology; biological analyses; radioecology • **Physics and Instrumentation:** meteorology; radiation dosimetry; instrumentation • **Chemistry and Separations Processes:** analytical chemistry; chemical effluents technology
1958* (GE 1958e, 1958f, 1958g, 1959b)	• **Biology Program:** aquatic biology; experimental animal farm; metabolism studies; pharmacology; plant nutrition and microbiology; radioecology • **Physics and Instrumentation:** meteorology; radiation dosimetry; instrumentation • **Chemistry and Separations Processes:** analytical chemistry; chemical effluents technology
1959 (GE 1960b)	• **Analytical and Counting Methods:** gamma ray spectrometric analysis; radiostrontium procedures with nitric acid; analysis of plutonium in urine; phosphorescence photons; determining radioactive ions in reactor effluent • **Bioassay Studies:** measurements of zinc • **Environmental Studies:** radioactivity in foods; measuring fallout radioisotopes on vegetation • **Reactor Studies:** the origin of effluent radioisotopes; sources of fission product radioisotopes in effluent; kinetics of arsenic retention; effects of temperature and flow velocity on the decontamination of reactor effluent • **Radiation Chemistry:** chemical protection from ionizing radiation; protolysis and hydrolysis reactions of erioglaucine in aqueous solutions; susceptibility of solutes to attack by free radicals in aqueous solution; electron-spin resonance studies; membrane electrode cell for the determination of dissolved oxygen

Year	Physical Science Research Projects (As Indicated by Annual Reports and with Asterisk by Quarterly Reports)
1960 (GE 1961b)	• **Atmospheric Physics:** diffusion and transport; tracer technology; dispersion measurements
	• **Radiological Physics:** radioactivity in Hanford employees; whole body counter; retention of radioisotopes; scanning counter; shadow shields; polyethylene long counter; radioactive neutron sources; Perlow neutron spectrometer; Van de Graaff accelerator helium ion source; positive ion accelerator target prep.; gamma ray source measurements; stopping power of aluminum for electrons; precision instrumentation for an electron; linearizing thermistor thermometer; data in calorimetry; liquid nitrogen level controller
	• **Radiological Chemistry:** analytical and counting methods – various; environmental studies – various; reactor studies – various; radiation chemistry – various
	• **Chemical Effluents Technology:** special geological studies – various; geochemical and geophysical research – various; effluents research and development – various; equipment and instrumentation – various
	• **Instrumentation:** contaminated air monitoring techniques; biology operation support instrumentation; dosimetry instrumentation; radiation detection development; general radiological monitor development; automatic monitoring and recording methods; special purpose instrument development
1961 (GE 1962b)	• **Atmospheric Physics:** diffusion and transport; deposition of airborne materials; vertical exchange coefficients and the vertical flux of matter; precipitation scavenging processes
	• **Radiological Physics:** shadow shield whole body counter; iodine-131 levels in human thyroids after nuclear fallout; factors influencing measurement of plutonium in wounds; retention of isotopes; detection of phosphorous-32 in vivo; precision long counter; radiation effects in BF3 tubes; neutron energy degradation; secular variation in neutron emission from plutonium; neutron moderator; target contamination; etc.
	• **Radiological Chemistry:** analytical and counting methods; radiation chemistry; environmental studies; reactor studies
	• **Chemical Effluents Technology:** soil chemistry, geochemistry; soil physics; geology; instrumental techniques; uranium oxidation and fission product volatility; micromeritics
	• **Instrumentation:** contaminated air monitoring techniques; biology support instrumentation; dosimetry instruments; radiation detection development; general radiological monitor and circuitry development; automatic monitoring and recording methods
1962 (GE 1963b)	• **Atmospheric Physics:** diffusion, deposition, and transport; precipitation scavenging processes; advances in tracer technology
	• **Radiological Physics:** whole body counters; cesium-137 in Eskimos; cesium-134 in Eskimos and fallout; cesium-137 urinary excretion by Eskimos; determination of phosphorous-32 in vivo; plutonium x-ray scintillation counters; pulse shape discrimination in fast neutron dosimetry; lithium sandwich fast neutron spectrometer; precision long counter; calibration of the polyethylene double moderator; cosmic-ray neutron measurements; film activation studies; calorimetric determination of antimony-124; heat output of plutonium; input and source impedance corrections in high precision voltmeter standardization
	• **Radiological Chemistry:** reactor studies; environmental studies; radiation chemistry
	• **Chemical Effluents Technology:** soil chemistry, geochemistry; soil physics; geology; radioisotopes as particles and volatiles; uranium oxidation and fission product volatility
	• **Instrumentation:** automatic monitoring and recording methods; general radiological monitoring and circuit development; dosimetry instrumentation; radiation detector development; contaminated air monitoring techniques
1963 (GE 1964b)	• **Atmospheric Physics:** prediction of environmental exposures; comparison of results of atmospheric diffusion; dispersion from elevated sources; precipitation scavenging processes; atmospheric tracer technology
	• **Radiological Physics:** radioactivity in Alaskan Eskimos; human uptake of cesium-137; determination of the avg. cesium-137 body burden of a population; scintillation counter for in vivo detection of plutonium; determination of phosphorous-32 in vivo; whole body counters; pulse shape discrimination; response of paired ion chambers; precision long counters; low energy fast neutrons; fast neutron medical facility & shielding; heat amplifier; theory on measurement on beams
	• **Radiological Chemistry:** radioanalytical models; reactor studies; environmental studies
	• **Chemical Effluents Technology:** soil chemistry, geochemistry; soil physics; geology; radioisotopes as particulates and volatiles

Year	Physical Science Research Projects (As Indicated by Annual Reports and with Asterisk by Quarterly Reports)
	• **Instrumentation:** automatic monitoring and recording methods; biology instrumentation; dosimetry instrumentation
1964 (PNL 1965b)	• **Atmospheric Physics:** model for diffusion and transport for a continuous release in stable atmosphere; measurements of dispersion; point source in an unstable atmosphere; atmospheric turbulence measurements; area dosage relationships; precipitation scavenging studies; sampler for recording concentration of airborne zinc sulfide; improvements in micrometeorological instrumentation • **Radiological Physics:** radioactivity measured in Alaskan Natives 1962-64; seasonal variations of cesium-137 in Alaskan Eskimos; Urinalysis for cesium-137; sodium-22 and iron-55 in people and food; radioactivity in an Eskimo; whole body counting; cesium-137 in Trappist monks; humans exposed to uranium mine atmospheres; etc. • **Radiological Chemistry:** radiation chemistry; radioanalytical methods; reactor studies; counting studies; environmental studies • **Chemical Effluents Technology:** soil chemistry and geochemistry; atmospheric radioactivity and fallout – aerosol studies • **Instrumentation:** radiological measurement methods and instrumentation; biological and biomedical instrumentation; dosimetry and atmospheric physics instrumentation
1965 (PNL 1966b, 1966c)	• **Atmospheric Sciences:** precipitation scavenging studies; Midas computer program for evaporation of falling drops and isentropic stream functions and trajectories; radio-telemetered meteorological and radiation observation network; instrumenting of the Queen Air aircraft for sampling of a zinc sulfide atmosphere tracer; prediction of exposures from an elevated source; spectral distribution of atmospheric turbulence • **Radiological Physics:** fast pulse averaging; time-resolved spectroscopy; specific ionization of monoenergetic protons in tissue-equivalent gas; grid-walled proportional counter; self-absorption in scintillation crystals; pulsed x-ray machine; local energy density and hit theory; long-term change of plutonium-beryllium neutron sources; local-energy-density distributions; calorimetric measurement of polonium-210; low energy fast neutron spectrometer; transition zone density; etc • **Radiation Chemistry:** determination of erythocyte size distribution; radiation induced hemolysis of erythrocytes; effect of chloride ion on the radiolysis of erioglaucine solutions; electron spin resonance detection instruments; cobalt-60 irradiator flow system for electron spin resonance long-lived organic radicals formed in irradiated aqueous solutions; reaction kinetics of free radicals • **Radiological Chemistry:** alpha-emitters in the Columbia; reduction of reactor effluent radionuclides; the effect of reduced alum addition on the removal of arsenic-75 at the KW reactor; ion exchange studies; seasonal variations in sediment deposition; use of zinc-65/cobalt-60 ratios to determine age and deposition rates; method for determination of phosphorous-32 and other radionuclides; behavior and transport of radionuclides in the Columbia; natural and artificial radionuclide concentration in farm produce; distribution and excretion of technetium in humans; lead-210 in Alaskan biological samples; etc.
1966 (PNL 1967b, 1967c)	• **Atmospheric Sciences:** lateral plume growth; diffusion studies; turbulence investigations; wake studies; instantaneous plume detection; precipitation scavenging studies; real-time sampling of airborne tracers with aircraft; meteorological analyses of PLUMBBOB nuclear tests; raindrop charge measuring systems; identification and measurement of hydrogen chloride gas in the atmosphere; krypton-85 as an atmospheric tracer; portable boom-type air sampler • **Radiological Chemistry:** tracers of atmospheric precipitation processes; atmospheric behavior of airborne radionuclides; krypton-85 as an atmospheric tracer; air sampling; gamma-ray spectrometer studies; trace elements in marine organisms and sediments; etc • **Radiological Physics:** instrumentation for time-resolved spectrometry; proton irradiation of gases; programmed distribution generator; whole-body counter design and calibration; film dosimeter performance criteria; etc
1967 (PNL 1968b, 1968c)	• **Radiological Chemistry:** trace elements absorption, content, and measurement; automatic real-time air monitoring; radionuclide distribution in salmon; use of photon spectrometry; liquid scintillation counting; etc. • **Radiological Physics:** hit theory; delta rays of heavy particles; microdosimetry; gas pressure control; etc. • **Earth Sciences:** landslide cause and significance; tectonic deformation and seismic activity; infrared imagery over surface water; palynology; geophysical evaluation of thick basalt sequences in the Pasco Basin; etc
1968 (PNL 1970b, 1970c)	• **Radiological Chemistry:** determination of trace levels of various elements in soft tissue; radionuclide distribution and concentration; radium and radiobarium measurement in seawater; iron-55 concentrations in sea organisms; transfer of airborne radionuclides; multielement analysis of aquatic organisms; etc.

Year	Physical Science Research Projects (As Indicated by Annual Reports and with Asterisk by Quarterly Reports)
	• **Radiation Chemistry:** rate constants of organic compounds; long-lived organic radicals formed by irradiation; flash photolysis
	• **Radiological Physics:** radiation dosimetry; hit theory and microdosimetry; energy absorption straggling, distribution, and spectra; pulse read ion chamber system; beam current regulator; fast pulse signal averaging; etc.
	• **Instrumentation:** solid state detectors; smoking control for canines; radon monitoring; tritium target scanning using surface contoured diodes; miniature high voltage supply; etc.
1969 (PNL 1970f, 1970g)	• **Atmospheric Sciences:** diffusion and transport; boundary layer studies; BOMEX studies; fallout studies; precipitation scavenging studies; radioisotopes as particles and volatiles; ecological micrometeorology and climatology
	• **Radiological Chemistry:** inhalation hazards to uranium miners; rates of deposition in Alaskan environ; physical and radiological chemistry of ocean solutions; geothermal ocean section study (GEOSECS); in-cloud scavenging; radioanalytical procedure development; radioactive fallout rates and mechanisms; iron-55 in the human population; radiation instrumentation
	• **Radiological Physics:** internal depositions of radionuclides in man; characterization of radiation-induced free radical reactions in aqueous systems; nuclear techniques in medical science; radiation dosimetry; radiation physics
1970 (PNL 1971c, 1971d)	• **Atmospheric Sciences:** precipitation scavenging studies; diffusion and turbulence studies; radioisotopes as particles and volatiles; ecological micrometeorology and climatology
	• **Radiological Chemistry:** inhalation studies; rates of deposition of airborne radionuclides in the Alaskan environment; physical and radiological chemistry of ocean solutions; geochemical oceans sections study (GEOSECS); in-cloud scavenging; radioanalytical procedure development; radioactive fallout rates and mechanisms; iron-55 and lead in human population of the world; radiation instrumentation; tracer studies in the Northeast Colorado Hail experiment program
	• **Radiological Physics:** internal depositions of radionuclides in man; characterization of radiation-induced free radical reactions in aqueous systems; nuclear techniques in medical science; radiation dosimetry; radiation physics
1971 (PNL 1972c, 1972d)	• **Atmospheric Sciences:** precipitation of scavenging tracers; raindrop trajectories; wind shear; precipitation washouts of various compounds; aerosol particle size distributions; isentropic trajectories; climatological measurements; radioactive particles; aircraft instrumentation; tracer studies; fallout rates and mechanisms; turbulence measurement studies; lab procedures
	• **Radiological Chemistry:** inhalation hazards to uranium miners; rates of deposition of airborne radionuclides in the Alaskan environment; physical and radiological chemistry of ocean solutions; geochemical oceans sections study (GEOSECS); in-cloud scavenging; radioanalytical procedure development; radioactive fallout rates and mechanisms; iron-55 and lead in the human population; radiation instrumentation; tracer studies in the METROMEX experiment; radionuclide decline in the Columbia River water
	• **Radiological Physics:** dosimetry of radionuclides in man; characterization of radiation-induced free radical reactions in aqueous systems; nuclear techniques in medical science; mechanisms of environmental exposure; radiological evaluation of post mortem tissue samples; radiation dosimetry; radiation physics
1972 (PNL 1973c, 1973d)	• **Atmospheric Sciences:** diffusion, deposition, and turbulence studies on various terrain and surface types; experimental and modeling efforts for deposition of particulates; resuspension of surface contamination; controlled tracer experiments; distribution of resuspended soil particles; removal of pollutants by wet scavenging processes; various scavenging experiments; METROMEX studies; global distribution of contaminants
	• **Radiological Chemistry:** inhalation hazards to uranium miners; fate and effects of radionuclides in Alaska; physical and radiological chemistry of ocean solutions; geochemical ocean sections study (GEOSECS); precipitation scavenging; radioanalytical procedure development; radioactive fallout rates and mechanisms; iron-55 in human populations; radiation instrumentation; tracer studies in the national hail research experiment; tracer studies in the metropolitan meteorological experiment; survey study of radionuclides and chemical pollutants; radionuclide decline in Columbia River water
	• **Radiological Physics:** characterization of radiation-induced free radical reactions; nuclear techniques in medical science; mechanisms of environmental exposure; evaluation of radionuclides in man; radiation dosimetry; radiation physics; radiation biophysics

Year	Physical Science Research Projects (As Indicated by Annual Reports and with Asterisk by Quarterly Reports)
1973 (PNL 1974c, 1974d)	• **Atmospheric Physics:** characterization of sources and ambient pollutants; transport, diffusion, and turbulence studies; atmospheric transformation processes; removal and resuspension processes (wet removal, dry deposition particles, and resuspension of particles); special studies (cooling tower and cooling pond atmospheric impact and ecological micrometeorology and climatology of the ALE Reserve)
	• **Instrumentation Technology:** radiation instrumentation – radiation chemistry; nuclear techniques in medical science
	• **Radiological and Chemical Physics:** radiation physics studies; radiation dosimetry; radiation biophysics
	• **Nuclear Medicine Technology and Other Health Applications:** nuclear powered prostheses; medical uses of isotopes
	• **Artificial Heart Program:** medical grade plutonium-238 from americium-241; recipient radiation exposure; population radiation exposure
1974 (PNL 1975c, 1975d)	• **Atmospheric Sciences:** survey of radioactivity and chemical pollutants studies; radioactive fallout rates and mechanisms studies; atmospheric aerosols and trace gases studies; regional transport of effluent studies; fallout phenomenology; Hanford regional meteorological studies; atmospheric diffusion, deposition, and transport phenomena; fundamental turbulence studies; tracer studies in the METROMEX experiment; precipitation scavenging studies; cooling tower and cooling pond atmospheric impact studies; radioisotopes as particles and volatiles; particle resuspension and translocation; ecological micrometeorology and climatology on the ALE Reserve
	• **Instrumentation Technology:** radiation instruments; in situ monitoring; activation analysis technology; chemical and molecular composition technology; environ pollution analysis; real-time measurement of airborne plutonium; nuclear techniques in medicine
	• **Radiological and Chemical Physics:** radiation physics studies; radiation dosimetry and radiation biophysics studies
	• **Analysis and Evaluation:** toxic substances in nuclear fuels; methodology for the assessment of social values
	• **Nuclear Medicine Technology & Other Health Applications:** nuclear powered prostheses; medical use of isotopes
	• **Artificial Heart Program**
1975 (PNL 1976c, 1976d)	• **Instrumentation Technology:** low-level radiological chemistry laboratory techniques; in situ monitoring; environmental pollution analysis; in situ pollutant measurements; trace constituent analysis by laser excitation; analytical techniques for measurement of technetium-99 in environmental samples; fast real-time measurement of extremely low-level airborne plutonium; environmental applications of holography; chemical reaction kinetics
	• **Radiological and Chemical Physics:** radiation physics; radiation dosimetry and radiation biophysics; dosimetry of particulate sources in the lung
	• **Health Protection:** dosimetry of internal emitters
	• **Analysis and Evaluation:** toxic substances in nuclear fuels; assessment of social values in thermal plant siting; considerations and methodologies for studies concerning the effect of low-level exposures to environmental contaminants
	• **Regional Studies:** Pacific Northwest regional assessment program
	• **Atmospheric Sciences:** survey of ambient airborne pollutants; radioactive fallout rates and mechanisms; atmospheric chemistry of coal conversion pollutants; chemical and physical properties of pollutants in the Colstrip power plant effluents; tracer studies – METROMEX; theoretical studies; atmospheric boundary layer studies; particle resuspension and translocation; radioisotopes as particles and volatiles; precipitation scavenging; aerosol and trace gas transformations; safety analysis and environmental effects studies; Pacific Northwest energy related regional assessment program; atmospheric impacts
1976 (PNL 1977c, 1977d)	• **Atmospheric Sciences:** surveys and weather modification; air flow and dispersion; deposition and resuspension; pollutant scavenging; pollutant transformations and interactions; composite models for atmospheric processes;
	• **Physics and Chemistry of Pollutant Interactions in the Environment:** reaction kinetics of combustion processes
	• **Radiological and Chemical Physics:** radiation dosimetry and radiation biophysics; dosimetry of particulate sources in the lung; radiation physics-basic collision cross sections, radioluminescence studies

Year	Physical Science Research Projects (As Indicated by Annual Reports and with Asterisk by Quarterly Reports)
	• **Characterization, Measurement, and Monitoring:** radiation instrumentation; environmental pollution analysis; oil shale and tar sand research; dosimetry of internal emitters; analytical techniques for technetium-99 measurement; trace constituent analysis by laser excitation; application to holography; real-time measurement of plutonium in air below MPC levels
1977 (PNL 1978c, 1978d)	• **Atmospheric Sciences:** precipitation scavenging in MAP3S; aerosols and trace gas transformations; MAP3S modeling studies; atmospheric boundary layer studies; particle resuspension and translocation; urban pollution characterization; transport and deposition; coal conversion pollutant chemistry; regional studies; air pollution dry deposition; comprehensive study of atmospheric diffusion prediction from meteorological parameters; alternate fuel cycle technologies; hemispheric pollution behavior studies of chemicals and radiation substances; fallout rates and mechanisms; meteorological effects of thermal energy releases (METER) • **Solar:** various studies • **Oil Shale:** dual tracer deposition; revised method of energy flux calculations; transport and dispersion in complex terrain; verification statistic for numerical models; etc. • **Coal:** formation of fly fish in coal combustion; mass spectrometric studies of gaseous effluents from in situ coal glassification • **Fission:** various studies • **Geothermal:** heavy-metal gaseous emissions from power plants; measurement of potentially toxic materials in geopressured geothermal fluids • **Multitechnology:** various studies
1978 (PNL 1979c, 1979d)	• **Atmospheric Sciences:** aerosol and trace gas transformations; precipitation scavenging in MAP3S; MAP3S modeling studies; regional studies; atmospheric boundary layer studies; coal conversion pollutant chemistry studies; particle resuspension and translocation; alternate fuel cycle technologies/thorium fuel cycle technologies; meteorological effects of thermal energy releases; fallout rates and mechanisms; air pollution dry deposition studies • **Radiation Physics:** initial interaction processes; track structure; energy transport; radiation dosimetry and radiation biophysics; microdosimetry of internal sources; dosimetry of internal emitters; real-time measurement of plutonium in air; analytical techniques for environmental sampling; radiation instrumentation • **Geothermal, Oil Shale & Coal Studies** • **Multitechnology:** environmental pollution analysis; pollutant characterization; applications of holography; certifies research materials
1979 (PNL 1980c, 1980d)	• **Atmospheric Sciences:** Project ASCOT; radiation measurements; tracer experiments; micrometeorological measurements; sulfur surface flux measurements; particle deposition studies; pollutant transformations and models; MAP3S studies; regional scale assessments; aircraft measurements/research; in-cloud conversion rates; wind and cloud studies; particle/gas deposition studies; deposition measurements; resuspension studies; airborne plutonium transport at Hanford; atmospheric radionuclide concentrations near Richland; Hanford dispersion model; research needs in the oil shale industry; atmospheric transport studies; Hanford turbidity • **Coal:** reaction kinetics of combustion products; solvent refined coal effluent/product characterization • **Radiation Physics:** initial interaction processes; track structure; energy transport; radiation dosimetry and radiation biophysics; microdosimetry and radiation biophysics; microdosimetry of internal sources; dosimetry of internal emitters; real-time measurement of plutonium in air at below-MPC levels; analytical techniques for measurement of technetium-99 in environmental samples; radiation instrumentation; magnetic field dosimetry development • **Geothermal:** heavy-metal and noxious-gas emission from geothermal resource development • **Oil Shale:** oil shale and tar sand research • **Multitechnology:** environmental pollutant characterization by direct-inlet mass spectrometry; trace analysis by laser excitation; direct coupled plasma emission spectroscopy; applications of holography
1980 (PNL 1981c, 1981d)	• **Atmospheric Sciences:** behavior of air pollution; types of pollutants emitted; transport and diffusion; physical and chemical transformations during transport; removal by wet and dry deposition processes; pollutant impacts on climate, bodies of water and organisms; deposition and resuspension studies of particulates; removal by deposition studies; oil shale studies

Year	Physical Science Research Projects (As Indicated by Annual Reports and with Asterisk by Quarterly Reports)
	• **Coal:** reaction kinetics of combustion products; modeling cellular effects of coal pollutants • **Fission/Radiation Physics:** initial interaction process; track structure; energy transport; radiation dosimetry and biophysics; microdosimetry of internal sources; dosimetry of internal emitters; radiological chemistry; magnetic field dosimeter development; transuranic chemical species in groundwater • **Geothermal:** heavy-metal and noxious-gas emission from geothermal resource development • **Oil Shale:** oil shale and tar sand research studies • **Multitechnology:** environmental pollutant characterization by direct inlet mass spectrometry; trace analysis by laser excitation; applications of holography
1981 (PNL 1982c, 1982d)	• **Atmospheric Sciences:** atmospheric diffusion in complex terrain; atmospheric boundary layer studies; pollutant transformation in the atmosphere; atmospheric carbon dioxide abundance; meteorological effects of thermal energy releases; theoretical studies and applications; air pollution dry deposition; particle resuspension and translocation; oil shale fugitive air emissions • **Coal:** reaction kinetics of combustion products; modeling cellular effects of coal pollutants • **Radiation Physics:** initial interaction process; energy transport; radiation dosimetry and biophysics; microdosimetry of internal sources; dosimetry of internal emitters; radiological chemistry; magnetic field dosimeter development • **Oil Shale:** oil shale and tar sand research studies • **Multitechnology:** environmental pollutant characterization by direct inlet mass spectrometry; trace analysis by laser excitation
1982 (PNL 1983c, 1983d)	• **Atmospheric Sciences:** pollutant characterization; boundary layer meteorology in complex terrain; dispersion, deposition, and resuspension of atmospheric pollutants; particle resuspension and translocation; theoretical studies and applications; oil shale fugitive air emissions • **Analytical Studies:** coal liquefaction product characterization; oil shale and tar sand research materials preparation and documentation • **Measurement and Dosimetry:** characterization of synfuels and combustion products; trace analysis by laser excitation; procedures development • **Radiation Physics:** initial interaction process; track structure; energy transport • **Dosimetry and Biophysics:** modeling and cellular studies; dosimetry; microdosimetry of internal emitters
1983 (PNL 1984c, 1984d)	• **Atmospheric Sciences:** transformation of energy related contaminants; atmospheric diffusion in complex terrain; atmospheric boundary layer studies; dry deposition; particle resuspension and translocation; theoretical studies and applications • **Analytical Studies:** chemical basis for the biological response to conversion materials; oil shale and tar sands research • **Measurement and Dosimetry:** characterization of synfuels and combustion products; lasers in analytical chemistry • **Radiation Physics:** initial interaction processes; track structure; radiation dosimetry; modeling and cellular studies; radiation biophysics; modeling cellular response to genetic damage; internal microdosimetry
1984 (PNL 1985c, 1985d)	• **Atmospheric Sciences:** atmospheric studies in complex terrain; atmosphere boundary layer studies; coupling/decoupling of synoptic and valley circulation; air pollution by dry deposition; oil shale fugitive air emissions and plume depletion; particle resuspension and translocation; theoretical studies and applications; processing of emissions by clouds and precipitation • **Analytical Studies:** chemical basis for the biological response to complex organic mixtures • **Measurement and Dosimetry:** supercritical fluid analytical methods; lasers in analytical chemistry • **Radiation Physics**: initial interaction processes; track structure; radiation dosimetry; modeling and cellular studies; radiation biophysics; modeling cellular response to genetic damage; internal microdosimetry

Year	Physical Science Research Projects (As Indicated by Annual Reports and with Asterisk by Quarterly Reports)
1985 (PNL 1986c)	• **Atmospheric Sciences:** atmospheric diffusion in complex terrain; coupling/decoupling of synoptic and valley circulation; atmospheric boundary layer studies; dry deposition and resuspension; processing of emissions by clouds and precipitation
1986 (PNL 1987c, 1987d)	• **Atmospheric Sciences:** atmospheric diffusion in complex terrain; coupling/decoupling of synoptic and valley circulation; atmospheric boundary layer studies; scavenging studies; Soviet accident fallout measurements
	• **Analytical Studies:** chemical basis for biological response to energy-related organics
	• **Measurement and Dosimetry:** supercritical fluid analysis methods; lasers in environmental research
	• **Radiation Biology:** initial interaction processes; track structure; radiation dosimetry; modeling and cellular studies; radiation biophysics; modeling cellular response to genetic damage
1987 (PNL 1988c, 1988d)	• **Atmospheric Sciences:** atmospheric studies in complex terrain; large-scale atmospheric transport and processing of emissions; measurement and analysis techniques; air-surface interaction
	• **Analytical Studies:** DNA adducts as indicators of health risks; Chernobyl database management
	• **Measurement and Dosimetry:** supercritical fluid analytical methods; lasers in analytical chemistry
	• **Physical Processes in Radiation Biology:** radiation physics – initial interaction processes, track structure; radiation dosimetry – dosimetry, modeling and cellular studies, radiation biophysics, modeling cellular response to genetic damage
1988 (PNL 1989c, 1989d)	• **Atmospheric Sciences:** atmospheric studies in complex terrain; large-scale atmospheric transport and processing of emissions; measurement and analysis techniques
	• **Analytical Studies:** Chernobyl database management
	• **Measurement and Dosimetry:** supercritical fluid analytical methods; lasers in environmental studies; laser measurements of lead-210; DNA adducts as indicators of health risks; biological effectiveness of radon particles
	• **Physical Processes in Radiation Biology:** radiation physics; radiation dosimetry; testing cell response models; radiation biophysics; modeling cellular response to genetic damage
1989 (PNL 1990c, 1990d)	• **Atmospheric Studies in Complex Terrain:** direct numerical simulation of turbulent boundary layer flows; modeling of slope flows; modeling and observations of a valley's heat budget; planning for Oak Ridge experiment; observations of thermally developed wind systems in mountainous terrain; atmospheric mass and heat budgets for a canyon land basin; use of a nonhydrostatic mesoscale model to simulate drainage flows in the presence of ambient winds
	• **Large-Scale Atmospheric Transport and Processing of Emissions:** precipitation chemistry observations; concentration and distribution of atmospheric peroxides over the Pacific; overview of the frontal boundary study; effect of uncertainty in RSM meteorological parameters on predicted pollutant wet deposition; MAP3S precipitation chemistry network; proposed test of two hypotheses related to concentration fluctuations
	• **Climate Change:** another Gremlin in the greenhouse (anthropogenic sulfur); preliminary analysis of deep convection in an ocean general circulation model; experiments on the influence of whitecaps on air/sea gas transport rates; second-generation model of greenhouse gas emissions; regional effects of climate change and carbon oxygen-2 fertilization on the natural and human environment
	• **Dosimetry Research:** Chernobyl database management; determination of radon exposure; DNA adducts as indicators of health risks; biological effectiveness of radon alpha particles; biological behavior and dosimetry
	• **Measurement Science:** capillary electrophoresis-mass spectrometry; lasers in environmental research
	• **Radiological and Chemical Physics:** radiation physics; radiation dosimetry; radiation biophysics; modeling cellular response to genetic damage
1990 (PNL 1991c, 1991d)	• **Atmospheric Research:** atmospheric diffusion in complex terrain; heat budgets of valley and basin atmospheres; atmospheric boundary layer studies; atmospheric chemistry program/PRECP; continuing development of the G-1 aircraft
	• **Climate Research:** atmospheric radiation measurement (ARM) program; carbon dioxide ocean research; progress report on the second generation model; resources analysis research project – MINK study

Year	Physical Science Research Projects (As Indicated by Annual Reports and with Asterisk by Quarterly Reports)
	• **Dosimetry Research:** Chernobyl database management; determination of radon exposure; DNA adducts as indicators of health risks; biological effectiveness of radon alpha particles • **Measurement Science:** capillary electrophoresis-mass spectrometry; lasers in environmental research • **Radiological and Chemical Physics:** radiation physics-various; radiation dosimetry-various; radiation biophysics-various; modeling cellular response to genetic damage-various